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EDITORIAL

The *Journal of Management* is a peer-reviewed applied sciences journal published by the Lithuania Business College. Since its establishment in 2002, the journal has continuously contributed to the dissemination of scholarly research in the fields of management, economics, and related social sciences. Over the years, it has developed an increasingly international profile, bringing together researchers from Lithuania and other countries. The current issue, Volume 42, continues this tradition by presenting research addressing contemporary challenges in management, organizational governance, digital transformation, sustainability, and the changing nature of work.The authors represent a diverse range of academic institutions in Lithuania and abroad, including Lithuania Business College, Klaipeda University, Kaunas University of Technology, Vilnius Business College and others, as well as Petro Mohyla Black Sea National University (Ukraine), Lviv Polytechnic National University (Ukraine), Uzhhorod National University (Ukraine), among others.

The Editorial Board seeks to ensure that the journal provides a platform for research that combines academic rigor with relevance to current organizational and societal challenges. Particular attention is given to transformations taking place in management practices, technological environments, labor markets, and organizational systems. The articles included in this issue reflect these priorities and demonstrate the interdisciplinary character of contemporary management research.

The article, authored by Rasa Žilienė, examines project management fragmentation in contemporary hybrid project environments. The study addresses the growing heterogeneity created by specialized digital platforms, decentralized teams, hybrid project-management methods, and multi-level governance arrangements. Based on an exploratory qualitative survey of experienced project-management professionals, the research identifies five dimensions of project management fragmentation: tool and system fragmentation, data and information fragmentation, methodological fragmentation, knowledge fragmentation, and governance and decision-right fragmentation. Coordination-related costs emerge as the most frequently reported consequence, while decision latency and rework are also identified as important downstream effects. The study proposes a Project Integration Governance framework based on information, technological, methodological, knowledge, and governance integration. An important contribution is the principle of Minimum Viable Standardization, according to which organizations should standardize the interfaces necessary for organizational coherence while preserving flexibility in team-level practices and specialized tools.

The article, by Gabija Skučaitė, focuses on AI-mediated platform work and the question of meaningfulness under algorithmic management. The conceptual study examines how artificial intelligence, platform-level control, and governance arrangements may shape the meaning workers attribute to particular work episodes. Drawing on research on gig work, algorithmic management, task-based labour economics, and meaningful work, the article distinguishes between AI substitution and augmentation at the task level and control intensification at the platform level. The proposed framework identifies four pathways through which meaningfulness may be experienced—individuation, self-connection, contribution, and unification—and outlines governance arrangements that may preserve or expand workers' opportunities to experience meaningful work. These include rule intelligibility, credible human contestability, worker voice, capability development, and relational infrastructure. The study provides a conceptual basis for future empirical investigation of meaningfulness in AI-mediated platform-work environments.

The article, authored by Olena Bochko, Nadiia Marushko, Olga Maletska, Orysya Voloshyn, and Olena Zarichna, examines digitalization, sustainable development, and marketing through the lens of scientometric analysis. Using data from the Scopus database and VOSviewer software, the study analyzes publication activity, thematic structures, and scientific collaboration networks in this interdisciplinary field. The analysis covers a substantial body of 3,657 publications and

demonstrates the rapid growth of scholarly interest, particularly after 2020. Several major thematic clusters are identified, including digital marketing and commerce; tourism and the performance of small and medium-sized enterprises; data analytics and machine learning; consumer behavior and supply chains; and trust, consumption psychology, and ESG-related issues. The findings also reveal an uneven and clustered structure of international and institutional scientific collaboration. The study provides benchmarks for understanding the evolution and current structure of research connecting marketing, digitalization, and sustainable development, particularly in the context of the global Sustainable Development Goals.

Taken together, the articles in this issue demonstrate how contemporary management research is increasingly shaped by technological transformation, organizational complexity, changing forms of work, and sustainability-related challenges. They illustrate the importance of integration—not only between technologies and organizational processes, but also between governance mechanisms, human experience, knowledge, and broader societal objectives.

The issue also highlights the growing importance of understanding management beyond traditional organizational boundaries. Hybrid project environments require new approaches to coordination and governance; AI-mediated work raises fundamental questions about human agency and meaningfulness; and the intersection of digitalization, marketing, and sustainability demonstrates how technological and economic transformations influence the development of scientific knowledge itself.

Through the publication of research addressing these emerging issues, the *Journal of Management* seeks to contribute to both academic discussion and managerial practice. We believe that the studies presented in this issue will be relevant to researchers, managers, policy makers, and other professionals interested in the transformation of contemporary organizations and management systems.

On behalf of the Editorial Board, we warmly invite researchers to continue submitting their original research, sharing theoretical and methodological insights, and engaging in international academic collaboration. Through such cooperation, the journal aims to support the development of management science and to promote research that responds meaningfully to the challenges of contemporary organizations and society.

As it is not possible to review all contributions in this Editorial, we encourage readers to explore the full range of studies presented in this issue. We hope that the published research will stimulate further discussion, inspire new research directions, and contribute to the continuing development of management and related social sciences.

Prof. Dr. (H/P) Valentinas Navickas, Editor-in-Chief

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DIGITALIZATION, SUSTAINABLE DEVELOPMENT AND MARKETING THROUGH THE LENS OF A SCIENTOMETRIC ANALYSIS OF RESEARCH TRENDS

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Abstract
In the context of the accelerated digitalization of economic processes and growing global challenges related to sustainable development, enterprises' marketing activities are increasingly shifting towards integrating commercial efficiency with environmental and social responsibility. In this context, scientific research at the intersection of marketing, digital transformation, and sustainable development has evolved rapidly over the past decade. However, most studies have focused on individual aspects, including digital marketing tools, green consumer behavior, the implementation of environmental, social, and governance (ESG) indicators, or technological drivers of digitalization. Despite the growing academic interest in these issues, the implications of these developments for the structure of the scientific literature have not yet been comprehensively examined from a scientometric perspective. This study analyzes publication activity, thematic structure, and scientific collaboration networks at the intersection of marketing, digitalization, and sustainable development over the period 2015–2026. Based on a unified dataset comprising 3,657 publications, the study examines chronological trends, international and institutional collaboration, co-authorship, and citation patterns while maintaining a consistent dataset across all analytical dimensions. To achieve the research objective, a bibliometric analysis was conducted for the specified period using Scopus, a widely recognized scientometric database, and VOSviewer software. The analysis confirms that the vast majority of scientific publications in this field were published after 2020. Between 2020 and 2025 alone, the annual number of publications increased from 92 to 1,006 documents, with publications from this period accounting for more than 80% of the entire dataset analyzed. Although no direct temporal correlation could be established between the adoption of specific strategic documents on sustainable development and the acceleration of publication activity, the findings indicate that the period 2022–2025 was characterized by the highest growth rates in scientific output compared with previous years. Furthermore, keyword density visualization revealed several thematic clusters within the research field connecting marketing, digitalization, and sustainable development: digital marketing and commerce; tourism and small and medium-sized enterprise performance; data analytics and machine learning; consumer behavior and supply chains; and trust, consumer psychology, and ESG-related issues. The analysis of international and institutional collaboration networks, together with co-authorship patterns, further confirmed the uneven and clustered nature of scientific collaboration, with research activity concentrated around a relatively limited number of countries, institutions, and authors. The findings, based on the most recent available data, provide an objective foundation for understanding the evolution, trends, and interconnections of academic research at the intersection of marketing, digitalization, and sustainable development. This research area is becoming increasingly important in the context of achieving the global Sustainable Development Goals (SDGs) by 2030.
KEYWORDS: digitalization; sustainable development; marketing; scientometric analysis; ESG; bibliometrics.
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Introduction

The development of digitalization in economic processes and the intensification of global sustainability challenges are transforming marketing activity into an instrument that combines commercial efficiency with environmental and social responsibility. Kwilinski (2023), analyzing 9,527 Scopus publications for 1990–2023, confirms the exponential growth of scholarly interest in the relationship between digital technologies and sustainable development, noting an annual publication growth rate of about 36% and identifying five evolutionary stages of this field. Andriansyah, Anshori and Andiyani (2023), based on a bibliometric analysis of 218 Scopus publications for 2019–2023, similarly show that research on digital marketing combined with technological innovation and sustainability peaks in 2023 (79 documents). In parallel, digitalization of marketing is increasingly viewed as a direct factor of enterprise sustainability. Diez-Martin, Blanco-Gonzalez and Prado-Roman (2019), reviewing the 2009–2018 literature, outline six key challenges at the intersection of digital marketing and sustainability: consumer orientation and value proposition, digital consumer behavior, digital "green" marketing, competitive advantage, supply chains, and organizational capabilities. Kumar, Sharma, Mishra, Sharma and Bhardwaj (2025), applying LDA topic modeling to 2,061 Scopus publications (1991–2025), show that digital technologies — IoT, blockchain, AI and digital platforms — catalyze the transformation of "green" marketing, forming clusters around sustainable consumption, digital marketing techniques, purchase intentions and green supply chains. Deng, Lan, Chen, Zheng and Zhang (2025), using structural equation modeling on data from 86 Chinese new-energy enterprises (2018–2022), demonstrate that digital transformation enhances sustainable marketing performance both directly and through strengthened market orientation.

Despite this growing body of work, a holistic conceptual model of the interaction among marketing, digital transformation and sustainable development remains underdeveloped. Existing studies mostly address one of the three areas in isolation — digital marketing, AI in marketing communications, or sustainable consumption — without a systemic, scientometrically grounded synthesis covering both leading databases (Scopus and Web of Science).

This study applies the bibliometric approach to analyze publications on the relationships among marketing activity, digital transformation and sustainable development, assessing the evolution of research priorities in digital marketing, the adoption of AI in marketing communications, and the integration of environmental and social responsibility into business practice.

Literature Review

The contemporary scholarly discourse on the relationship between marketing, digitalization and sustainable development is formed at the intersection of several research directions: sustainable and green marketing, digital marketing, digital business transformation, sustainable consumption, and digital technologies. Analysis of publications in recent years indicates a gradual shift from the study of individual marketing tools toward a comprehensive examination of digital technologies as a factor transforming the models of value creation, communication and consumption.

One of the directions that has formed the methodological foundation of contemporary research is the rethinking of the concept of sustainable marketing. Dyck and Manchanda (2021) examine sustainable marketing through the lens of virtue ethics, emphasizing the need to shift marketing orientation from short-term economic gain toward taking into account broader socio-ecological consequences of economic activity. Prothero and McDonagh (2021), in turn, develop the discussion on the ethical foundations of sustainable marketing and its compliance with contemporary social and environmental challenges. This approach broadens the traditional interpretation of marketing; however, it has a certain limitation: normative and ethical provisions do not always translate into measurable indicators of marketing performance. Thus, early studies of sustainable marketing largely concentrate on the conceptual substantiation of its principles, while the issue of quantitative evaluation of results remains insufficiently developed.

In parallel, a research line is being formed in which digitalization is regarded as a factor ensuring sustainability. George et al. (2021) link digital sustainability with entrepreneurship and the use of digital innovations to respond to climate and social challenges. Knudsen et al. (2021) investigate the impact of digitalization on the sustainability of competitive advantage, demonstrating that digital technologies can alter the mechanisms of forming and maintaining enterprises' competitive positions. Gomez-Trujillo and Gonzalez-Perez (2022) directly examine digital transformation as a strategy for achieving sustainability. The distinction of these approaches lies in the fact that digitalization is no longer confined to the functional improvement of business processes but is instead considered in connection with long-term economic, environmental and social outcomes.

This direction was systematized by Guandalini (2022), who, on the basis of a systematic literature review, investigates the relationship between digital transformation and sustainable development. The author shows that digitalization can contribute to the achievement of sustainable development goals by increasing resource-use efficiency, fostering innovation, and transforming business models. At the same time, digital transformation does not have an unambiguously positive effect: its results depend on the organizational context, the nature of the technologies, and enterprises' ability to integrate digital solutions into an overall sustainable development strategy. This conclusion is of fundamental importance for marketing research, since the use of digital channels per se does not ensure the sustainability of marketing activity.

A separate body of literature is devoted to green marketing. Sharma (2021) systematizes research on consumer behavior and green marketing, demonstrating a close relationship among environmental attitudes, marketing stimuli and consumer intentions. Kaur et al. (2022) deepen this direction through an analysis of the relationship among green marketing strategies, environmental attitude and green purchase intention. Majeed et al. (2022) focus attention on the mediating effect of green brand image and consumers' environmental beliefs. García-Salirrosas and Rondon-Eusebio (2022) likewise link enterprises' marketing practices to consumers' behavioral characteristics.

Thus, existing studies provide a broad framework for explaining green purchase intention, but primarily focus on end-consumer behavior. The role of digital channels in modifying the influence mechanisms of green marketing messages remains insufficiently explored. Alkhatib et al. (2023), through a systematic review of green marketing in the digital age, demonstrate the gradual convergence of green and digital marketing during 2012–2022. Their findings indicate a shift from communicating environmental product characteristics toward the use of digital channels, social media and online consumer interaction, although the review largely reflects an earlier stage of digitalization. Therefore, further research is needed to examine contemporary issues such as AI, algorithmic personalization, influencer marketing, digital transparency and platform-based business models.

A more systematic view of the evolution of green marketing was presented by Bhardwaj et al. (2023), who conducted a bibliometric analysis of research for 2005–2022. The advantage of this work is the ability to trace not individual results of empirical studies but the structure of the scientific field, its thematic dynamics, and the relationships among research directions. At the same time, the considerable length of the period studied reduces the possibility of characterizing the very latest trends in detail. For an article focused on 2021–2025, the results of Bhardwaj et al. should be regarded as a baseline point of comparison rather than as a sufficient reflection of the current state of research.

Liu et al. (2023) similarly examine green marketing through a CiteSpace-based bibliometric analysis, identifying approximately 952 Web of Science publications during 2019–2023 and highlighting the structure of relationships among key concepts. However, the study focuses primarily on green marketing, leaving the digital dimension less systematically explored. This limitation creates an opportunity to broaden the bibliometric perspective by integrating digital marketing, digital transformation, digital sustainability, ESG and sustainable development. In 2023–2024, research increasingly shifts from the digitalization of individual marketing processes toward its implications for sustainable business models, innovation and enterprise performance, as demonstrated by Broccardo et al. (2023), Lu et al. (2023) and Xu et al. (2023). Consequently, digitalization is increasingly conceptualized not merely as a technological characteristic but as a mechanism for transforming the creation of economic and environmental value.

Particularly important for contemporary discourse is the work of Wang and Esperança (2023), which examines the impact of digital transformation on the market and ESG performance of small and medium-sized enterprises. This approach broadens the traditional understanding of digital marketing, since it links digital changes not only to communication effectiveness but also to non-financial outcomes of the enterprise. However, in this case ESG indicators remain predominantly an outcome characteristic of activity, while the specific contribution of marketing communications to their formation requires separate investigation.

In 2024, the direction associated with the convergence of digitalization and sustainable development intensifies. Mendez-Picazo et al. (2024) analyze the direct and indirect effects of digital transformation on sustainable development in the pre-pandemic and post-pandemic periods. Valero-Gil et al. (2024) focus attention on the convergence of digitalization and sustainability, which indicates the gradual formation of an integrated research field. Chen et al. (2024) examine the relationship between digital transformation and ESG decoupling, while Zhang and Huang (2024) investigate the role of supply chain resilience in the relationship between digital transformation and ESG performance. Taken together, these works demonstrate the expansion of the research subject from marketing activity to the entire system of corporate sustainability.

One of the new directions is the use of artificial intelligence in digital marketing. Gündüzyeli (2024) examines AI in digital marketing within the framework of sustainable management. At the same time, a methodological problem arises: digital technologies can simultaneously increase the effectiveness of marketing communications and generate new risks associated with excessive personalization, data privacy, digital inequality and the ethics of algorithmic decisions. Consequently, evaluating sustainable digital marketing requires taking into account not only economic outcomes but also social and ethical consequences.

Particular attention should be given to research published in 2025, which reflects the growing institutionalization of sustainable digital marketing (SDM). Rosário and Dias (2025), based on a systematic review of 84 Scopus publications, identify personalized messages, social media, influencer collaborations, environmental brand positioning and digital content as key mechanisms influencing sustainable consumer behavior, while also highlighting gaps concerning digital accessibility and ethical data management. Bashar et al. (2025) further develop the conceptualization of SDM by combining systematic review and bibliometric analysis, linking it to sustainable consumption, eco-friendly behavior, CSR, social equity, environmental education and sustainable business models. These studies demonstrate that sustainable digital marketing extends beyond the use of digital channels to promote environmentally friendly products and represents a broader integration of economic, social and environmental objectives. At the same time, the broad temporal coverage of existing reviews limits their ability to capture the most recent dynamics, highlighting the need for updated research on the evolution and integration of digital marketing and sustainable development.

Another aspect is presented by Ezeh and Dube (2025), who used VOSviewer for a bibliometric analysis of green and sustainability marketing. The authors focus attention on such concepts as sustainability marketing, green marketing, environmental responsibility, consumer attitudes, green products, green supply chain management, CSR and greenwashing. Digitalization does not act as a central category of this model, which leaves room for further research into the digital mechanisms of building trust in sustainability claims.

In parallel, the Digital ESG direction is being formed. Tan et al. (2025) conducted a bibliometric analysis of 455 documents indexed in Scopus devoted to the relationship between ESG and digitalization. The authors note the absence of a unified theoretical framework for Digital ESG and identify the main thematic directions of the development of this research field. This is of direct relevance to marketing research, since digital channels are increasingly used for ESG communications, the disclosure of non-financial information, and the formation of corporate reputation. At the same time, research on Digital ESG predominantly concentrates on corporate governance and reporting, while the marketing dimension of ESG communications remains less systematized.

An even broader approach was proposed by Kumar and Shah (2025), who combined a systematic review with a bibliometric analysis of 589 publications from Scopus and Web of Science for 2018–2025. The study shows a substantial acceleration of scholarly activity after 2020, and among the technological drivers it identifies AI, blockchain and IoT. The thematic clusters encompass digital governance, ESG transparency and the circular economy. At the same time, regional disproportions and an insufficient number of empirical studies in a number of sectors and countries were identified. The findings obtained make it possible to interpret Digital ESG as a

direction that extends beyond corporate reporting and is gradually integrating with the broader SDG agenda.

Thus, the literature analysis makes it possible to identify three stages in the evolution of the research discourse. The first is characterized by the predominance of the concepts of green and sustainable marketing and a focus on the environmental behavior of consumers. The second is associated with the digitalization of marketing communications and the integration of digital marketing with green marketing. The third, most pronounced in 2024–2025, entails the formation of an integrated field at the intersection of sustainable digital marketing, digital transformation, ESG and the SDGs.

Consequently, what remains insufficiently studied is not so much each of the aforementioned directions individually as their structural interaction within a single scientific field. In particular, the relationships among digital marketing technologies, sustainable consumption, ESG communications, greenwashing, artificial intelligence and the achievement of the SDGs require further analysis. Moreover, most existing bibliometric studies use different time frames, databases and search strategies, which complicates a direct comparison of their results.

It is precisely this circumstance that substantiates the expediency of conducting the present scientometric analysis of publications for 2021–2025 in Scopus using a unified search based on the keywords "marketing," "digitalization" and "sustainable development." Such an approach makes it possible to determine not only the dynamics of publication activity but also the structure of thematic clusters, keyword relationships, and co-authorship and citation networks. In this context, bibliometric analysis becomes an instrument for identifying structural changes in the research field rather than merely a method of quantitatively describing publications.

Research Methods

The empirical basis was formed on the basis of the international Scopus scientometric database, which is characterized by a high level of structuring of bibliographic data, broad disciplinary coverage, and standardized metadata. The choice of this database is due to its extensive use in bibliometric studies of related problem areas and its capacity to enable multi-level analysis of scholarly publications. Compared with other sources of scientific information, Scopus provides a more representative reflection of the international scientific space, which is important for the analysis of interdisciplinary research in the field of marketing, digitalization and sustainable development.

The empirical basis of the study was developed through a systematic search of scientific publications indexed in the Scopus database. The search strategy was designed to identify studies addressing the intersection of marketing, digitalization, and sustainable development. The search was conducted across publication titles, abstracts, and author keywords using the following combination of terms: (“marketing” OR “digital marketing” OR “green marketing”) AND (“digitalization” OR “digital transformation”) AND (“sustainable development” OR “ESG”).

This search configuration was selected to ensure the inclusion of publications in which marketing activities, digital transformation processes, and sustainability-related issues are examined within a common conceptual or analytical framework. The search was performed in Scopus on 3 September 2026.

The inclusion criteria covered peer-reviewed journal articles published in English and available in their final publication version. Records not corresponding to these criteria were excluded from the dataset. To improve data quality and ensure the consistency of the bibliometric sample, the retrieved records were additionally checked for duplicate entries. In addition to the automated data-processing procedures available in Scopus, a manual verification of bibliographic metadata was carried out to identify possible inconsistencies in publication records.

Scopus was selected as the primary data source because of its broad multidisciplinary coverage, standardized bibliographic structure, extensive citation data, and availability of metadata suitable for bibliometric and scientometric analysis. These characteristics make the database appropriate for examining interdisciplinary research trends and collaboration patterns at the intersection of marketing, digitalization, and sustainable development.

Although Web of Science is also widely used in bibliometric research, the present study was deliberately limited to Scopus in order to maintain methodological consistency within a single bibliographic environment. Combining data from Scopus and Web of Science would require additional procedures for data harmonization, duplicate removal, author and institutional disambiguation, and standardization of metadata structures. Therefore, cross-database comparison and integration are considered a potential direction for further research.

The final dataset comprised 3,657 publications. The dataset represents a static snapshot of Scopus indexing as of 3 September 2026 and was not updated during the subsequent stages of analysis. Accordingly, all bibliometric indicators presented in the study refer to this fixed dataset.

The analysis covered the period from 2015 to 2026 and included the examination of publication dynamics, thematic structure, citation patterns, co-authorship, international scientific collaboration, and institutional cooperation. A single dataset was retained throughout all analytical stages in order to ensure comparability of the results and to avoid changes in the composition of the sample depending on the specific dimension of bibliometric analysis.

Particular caution was applied to the interpretation of data for 2026. As the dataset was retrieved before the end of the calendar year, the number of publications indexed for 2026 (794 documents) is preliminary and should not be interpreted as a complete annual publication output. The corresponding value reflects only the publications indexed in Scopus as of the date of data retrieval.

The collected array of publications covers 3,657 sources with a time span corresponding to the period of formation of the scientific discourse on the problems of digital marketing and sustainable development (approximately 2015–2026), which provides the capacity to analyze long-term trends in the development of scientific thought in the field of the digital transformation of marketing practices and their alignment with the principles of sustainable development.

VOSviewer software was used for the visualization and analysis of the bibliometric data, providing for the construction of networks of relationships among keywords, co-authors, cited publications and bibliographic links (Broccardo, L., Zicari, A., Jabeen, F., and Bhatti, Z.A., 2023). The application of this tool provides the capacity to identify thematic clusters, determine the centers of scientific activity, and map the structure of research directions at the intersection of marketing, digitalization and sustainable development.

Bibliometric analysis is a descriptive method of studying scientific communication, as its primary object is the body of scientific publications and their structural characteristics rather than the economic, marketing, environmental, or social processes discussed in those studies. Accordingly, the results can be interpreted at two main levels: a descriptive level, covering publication volume, temporal dynamics, and subject-area distribution based on Scopus metadata, and a structural level, including thematic clusters, co-authorship, institutional collaboration, and citation networks identified through VOSviewer. These findings provide an empirical basis for characterizing the organization and relationships within the research field, while remaining subject to the methodological limitations of bibliometric analysis.

At the interpretative level, bibliometric data may indicate emerging research trends and relationships between digital transformation, marketing, sustainability, and related areas; however, they cannot independently establish causal effects on firms' economic, environmental, or social performance. Such findings should therefore be treated primarily as a basis for generating research hypotheses, while their empirical verification requires additional methods, including panel econometric analysis, structural equation modelling, or sector-specific case studies. Thus, bibliometric results are mainly used to describe the dynamics and structure of the scientific field, whereas conclusions regarding the real-world effects of digitalization require further empirical testing.

Research Results

Analysis of the chronological dynamics of publications on the topic of marketing, digitalization and sustainable development (Fig. 1) indicates a gradual expansion of scholarly interest in this problem area. In 2015–2019, the number of publications remained relatively low, ranging from 1 to 38 documents per year, which characterizes the initial stage of the formation of this interdisciplinary research direction.

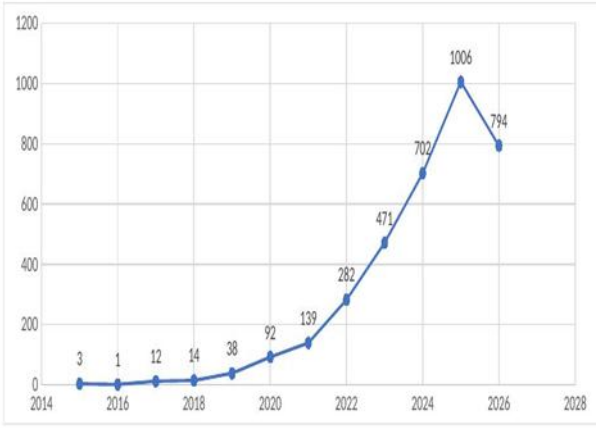


Fig. 1. Dynamics of the number of scholarly publications retrieved using the terms "marketing," "digitalization" and "sustainable development," 2015–2026, (the 2026 figure is preliminary, as of 3 September 2026)
Source: compiled based on Scopus data

Starting in 2020, a substantial acceleration of publication activity is observed: the number of documents grew from 92 in 2020 to 139 in 2021, 282 in 2022, 471 in 2023, and 702 in 2024. The highest figure was recorded in 2025 - 1006 publications - indicating a substantial intensification of scholarly attention to the relationship among marketing practices, digital transformation and sustainable development. In 2026, the Scopus database already contains 794 documents; however, this figure is not final, since the year has not yet ended.

Thus, over the period studied, a steady upward trend in publication activity can be traced. Particularly intensive growth occurs in 2020–2025, when the digitalization of business processes, sustainable development, ESG orientation and the transformation of marketing models became the subject of active interdisciplinary research.

To assess the dynamics of publication activity over the 2020–2025 period, the compound annual growth rate (CAGR) was calculated at 61.3%, reflecting an increase from 92 publications in 2020 to 1006 publications in 2025.

The dynamics of publications indicate a transition from the separate study of digital marketing and sustainable development toward a comprehensive investigation of their interrelationship, in particular in the context of sustainable consumption, digital technologies, ESG, and the digital transformation of business.

Given the descriptive nature of the study and the absence of an experimental assessment of causal relationships, the identified correlation between the adoption of strategic documents in the field of sustainable development and the dynamics of publication activity cannot be interpreted as evidence of a causal effect. It reflects only the statistical correspondence between temporal changes in the indicators under study.

Assessing the existence and nature of such a relationship requires the application of an interrupted time series analysis, accounting for the overall trend in publication activity, changes in indexing practices, and

the time lag between the adoption of strategic documents and their potential reflection in scientific publications. Considering the duration of the publication cycle in the social and economic sciences, a lag of approximately 12–24 months should be taken into account.

According to Fig. 2, the problem area under study is characterized by pronounced interdisciplinarity. The largest number of publications falls within Business, Management and Accounting - 1,975 documents, Social Sciences - 1,079, and Economics, Econometrics and Finance - 1,042. This structure confirms the predominance of an economic-and-managerial approach, within which marketing, digital transformation and sustainable development are regarded as interrelated components of contemporary business models.

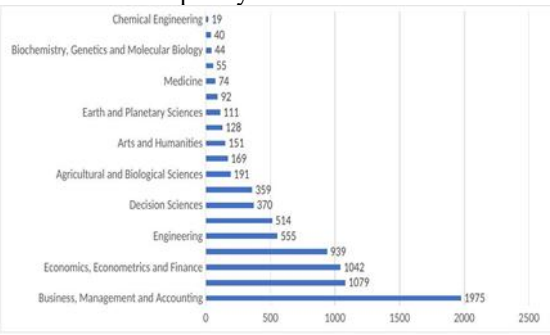


Fig. 2. Structure of the number of scholarly publications by subject area, retrieved using the terms "marketing," "digitalization" and "sustainable development," 2015–2026, (the 2026 figure is preliminary, as of 3 September 2026)
Source: compiled based on Scopus data

Also substantially represented are Computer Science - 939 documents, Engineering - 555, and Environmental Science - 514. Their combination reflects the technological and environmental components of the research, in particular the use of digital technologies, the development of digital business processes, the greening of activity, and the formation of sustainable business models. Fewer publications are concentrated in Decision Sciences (370), Energy (359) and Agricultural and Biological Sciences (191), which indicates the expansion of the research field into related directions.

Overall, the distribution of publications by subject area attests to the interdisciplinary character of contemporary research in the field of marketing, digitalization and sustainable development. The combination of managerial, economic, social, technological and environmental directions reflects the gradual formation of a comprehensive scientific discourse in which digital marketing tools are considered in relation to economic efficiency, environmental responsibility and the long-term sustainability of business.

The network of scientific collaboration by country in the field of marketing, digitalization and sustainable development (Fig. 3) demonstrates a geographically extensive structure of research activity and the formation of several interconnected clusters.

The largest nodes of the international scientific collaboration network are the United Kingdom, India, Indonesia, Portugal, Spain and Ukraine, which indicates high publication activity and established interstate links in research on marketing, digitalization and sustainable development.

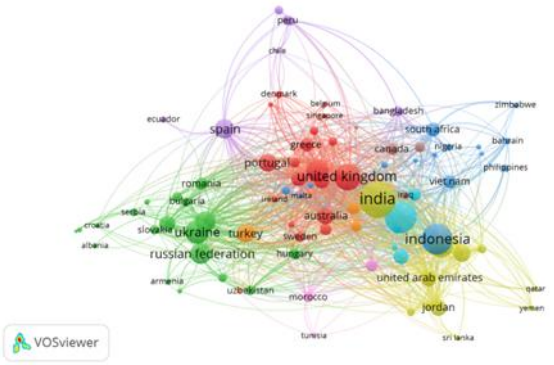


Fig. 3. Mapping of the international scientific collaboration network of countries in the field of marketing, digitalization and sustainable development, 2015–2026, (the 2026 figure is preliminary, as of 3 September 2026)
Source: compiled based on Scopus data using VOSviewer software

The central position of the United Kingdom and its numerous links with European, Asian and African countries characterize it as one of the main centers of international cooperation. The considerable presence of India and Indonesia reflects the activation of the Asian scientific community in this problem area.

The European segment of the network unites the United Kingdom, Portugal, Spain, Greece, Denmark, Belgium, Ireland, Sweden, Hungary and Romania, forming a dense environment of scientific interaction. Ukraine is integrated into a separate European–Eastern European direction and has links with a number of countries in the region, which attests to its participation in the international research space.

Overall, the network structure is characterized by a high density of international links and the absence of isolated national groups. At the same time, the concentration of the largest nodes in the United Kingdom, India, Indonesia, Portugal, Spain and Ukraine demonstrates an uneven distribution of scientific activity. The geographical structure of the network also attests to a gradual transition from the separate study of digital marketing and sustainable marketing toward interdisciplinary research on their relationship in the context of ESG, sustainable consumption and the digital transformation of the economy.

Visualization of the institutional collaboration network in the field of marketing, digitalization and sustainable development (Fig. 4) demonstrates the formation of two main clusters, characterized by different density and structure of relationships. The red cluster brings together mainly units associated with research on electronic marketing, in particular the *Department of Electronic Marketing*, the *College of Business Administration*, *INTI International University*, and related structural units. The green cluster is represented by the *Faculty of Business and Communication* and related smaller nodes.

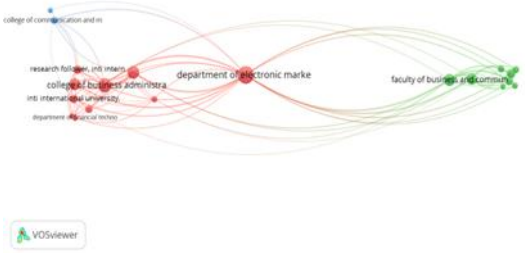


Fig. 4. Mapping of the international scientific collaboration network of organizations in the field of marketing, digitalization and sustainable development, 2015–2026, (the 2026 figure is preliminary, as of 3 September 2026)
Source: compiled based on Scopus data using VOSviewer software

The network structure is characterized by a concentration of links around individual institutional centers. The greatest density of interactions is observed within the red cluster, which attests to established research links among the units and institutions represented in the sample. At the same time, the presence of links between the red and green clusters attests to their interaction and the formation of inter-institutional channels of cooperation. A separate light-blue node, *College of Communication...*, which has a limited number of links, characterizes a peripheral segment of the network.

Overall, the resulting network attests to an uneven and clustered structure of institutional collaboration in research on marketing, digitalization and sustainable development. Scientific interaction is concentrated around individual university units and research groups, while part of the institutions occupy a peripheral position. Such a configuration characterizes the contemporary scientific discourse as one formed through a combination of localized research hubs with inter-institutional links among them.

The co-authorship network of the most productive authors in research on marketing, digitalization and sustainable development, presented in Fig. 5, reflects the structure of established scientific links among the authors whose publications were included in the analyzed Scopus sample. The visualization demonstrates the presence of two clusters, which differ in the level of internal integration and the intensity of co-authorship links.

The most developed is the red cluster, within which a dense collaboration network has formed around the authors Al-Babneh, Hassan Ali, Alrhaimi, Salem A. S., Mohammad, Suleiman Ibrahim, and Vasudevan, Asokan. The largest nodes of these authors and the numerous links among them attest to a higher intensity of joint publication activity. This research group also includes Al Adwan, Muhammad Noor, and Aburuman, Asad, who have links with the central participants of the network but are characterized by fewer co-authorship interactions.

A separate green cluster is represented by the authors Al-Daoud, Khaleel Ibrahim; Mohammad, Suleiman Ibrahim Shlash; and Mohammad, Anber Abraheem Shlash. This group is characterized by close internal links; however, its integration with the overall network is less pronounced.

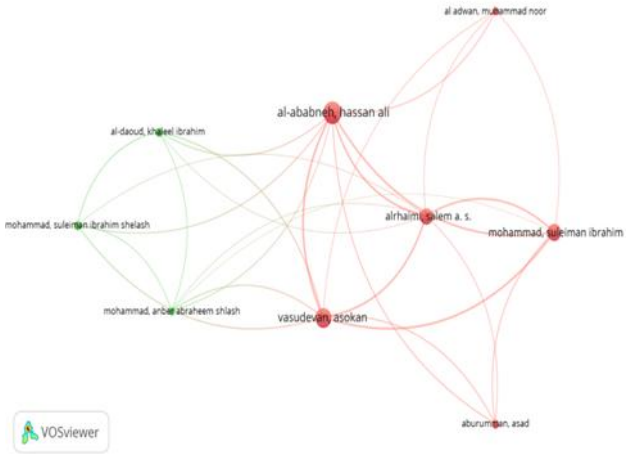


Fig. 5. Co-authorship network of researchers in the field of marketing, digitalization and sustainable development, 2015–2026, (the 2026 figure is preliminary, as of 3 September 2026)
Source: compiled based on Scopus data using VOSviewer software

Overall, the structure of the co-authorship network is characterized by a concentration of scientific collaboration around a limited group of authors who form the centers of research activity. The predominance of one denser cluster alongside a separate smaller group attests to the relative fragmentation of international scientific cooperation in research on marketing, digital transformation and sustainable development. At the same time, the presence of inter-cluster links attests to the interpenetration of thematic directions and the formation of broader research networks combining the problem areas of digital technologies, marketing practices and sustainable development.

Fig. 6 shows a polycentric structure of the author network, within which the main concentration of nodes forms the dominant core of research on marketing, digitalization and sustainable development. The most represented clusters are those associated with strategic management and dynamic capabilities theory, digital technologies and artificial intelligence, marketing and brand management, and tourism and sustainable development. Their mutual arrangement attests to a combination of several scientific traditions within the subject field under study.

Individual clusters, in particular those formed around Pimonenko T., Mohammad A.A.S./Al-Ababneh H.A., and Chiu D.K.W./Chan C.T., occupy a more peripheral position and have a limited number of links with the central part of the network. This characterizes the relative autonomy of the corresponding thematic directions and, at the same time, attests to the insufficient integration of individual research groups into the overall structure of scientific relationships.

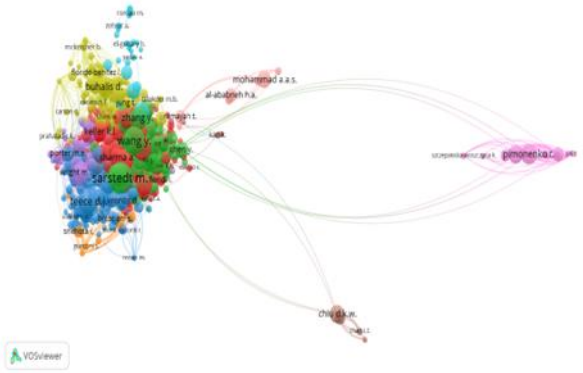


Fig. 6. Citation network of researchers in the field of marketing, digitalization and sustainable development, 2015–2026, (the 2026 figure is preliminary, as of 3 September 2026)
Source: compiled based on Scopus data using VOSviewer software

The distribution of node sizes demonstrates an uneven concentration of scientific activity and citation influence: the most represented authors form the core of the thematic discourse, while a significant proportion of researchers occupy peripheral positions. Such a structure reflects a combination of established theoretical approaches with newer directions associated with digitalization, sustainable consumption, artificial intelligence, and the transformation of business models.

Overall, the resulting network characterizes research on marketing, digitalization and sustainable development as an interdisciplinary and polycentric scientific field in which, alongside established research hubs, specialized thematic clusters emerge. The presence of weakly integrated directions attests to the promising nature of further combining marketing, digital and ESG-oriented research and expanding interdisciplinary scientific cooperation.

Fig. 7 shows a network visualization constructed on the basis of keyword co-occurrence analysis, which represents the thematic structure of the scientific field at the intersection of marketing, digitalization and related research directions. In accordance with the methodological principles of constructing such maps, node size is proportional to the frequency of use of the corresponding term in the analyzed array of publications, the thickness of the connecting lines reflects the strength of the semantic relationship between concepts, while color coding (five clusters identified) indicates the belonging of terms to relatively independent thematic groupings.

The peripheral position of nodes associated with sustainable development issues, such as “carbon footprint” and “ESG market”, together with their lower representation compared with dominant terms such as “marketing”, “digital marketing”, and “commerce”, indicates that sustainability-related terminology is not yet fully integrated into the core of the examined terminological space. This configuration reflects the level of lexical representation of sustainable development issues within the marketing research discourse, but it does not provide sufficient grounds for assessing the extent of their practical implementation by firms.

The relationship between scientific discourse and marketing practice requires separate empirical verification, since keyword co-occurrence analysis does not make it possible to determine either the nature or the intensity of this relationship.

Analysis of the network topology makes it possible to identify five substantively differentiated clusters. The red cluster ("covid-19," "literature review," "bibliometric analysis," "sharing economy," "case study," "China") combines a methodological component (bibliometric and literature reviews) with the topic of pandemic-driven transformations of business models, in particular the sharing economy.

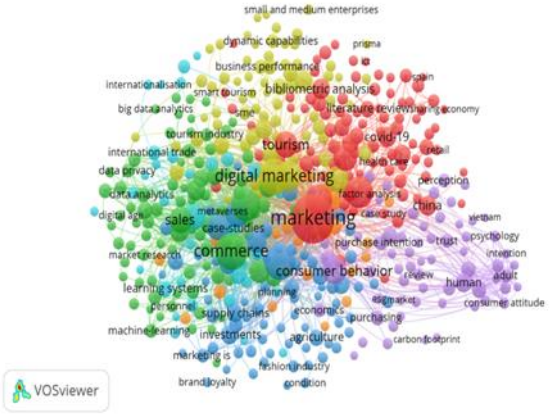


Fig. 7. Network of keyword relationships in the field of marketing, digitalization and sustainable development, 2015–2026, (the 2026 figure is preliminary, as of 3 September 2026)
Source: compiled based on Scopus data using VOSviewer software

The olive-yellow cluster ("tourism," "SME," "business performance," "dynamic capabilities," "smart tourism," "internationalisation") forms a direction associated with the impact of digitalization on the performance and internationalization of small and medium-sized enterprises, in particular in the tourism industry. The green cluster ("sales," "case-studies," "data analytics," "machine-learning," "learning systems," "market research") represents a technologically oriented component — the application of data analytics and machine learning in marketing research and sales. The blue cluster ("consumer behavior," "supply chains," "investments," "agriculture," "brand loyalty," "fashion industry") encompasses applied sectoral studies of consumer behavior and supply chains, while the purple cluster ("human," "trust," "psychology," "consumer attitude," "purchase intention," "esg market," "carbon footprint") concentrates the psychological determinants of consumer behavior in connection with environmental and ESG issues.

Notably, the term "marketing" acts as a bridging node among all five clusters, which confirms the integrative, interdisciplinary character of the field under study: the marketing problem area simultaneously intersects with technological innovation (data analytics, artificial intelligence), the economic sustainability of enterprises

(dynamic capabilities, business performance), and environmental and social responsibility (carbon footprint, ESG market).

Research limitations

The interpretation of the obtained results requires consideration of methodological limitations related to the source of bibliographic data, the parameters used to construct the sample, and the specific characteristics of the bibliometric indicators applied. Taken together, these factors may affect the structure of the identified research field; therefore, the findings should be interpreted within the boundaries of their representativeness.

The empirical basis of the study was constructed exclusively using Scopus data. Despite the broad disciplinary coverage of this database, its indexing policy may result in the uneven representation of regional and non-English-language scientific journals. Consequently, the geographical concentration of publication activity identified within the analysed dataset may partly reflect the characteristics of Scopus indexing coverage rather than solely the actual intensity of research activity in individual countries. Applying the same search strategy to Web of Science or Google Scholar data in future studies would make it possible to assess the robustness of the identified geographical and thematic patterns.

An additional limitation concerns the language of publication. The inclusion of English-language publications only restricts the coverage of research findings published in national languages and may reinforce the geographical asymmetry of the resulting dataset. Under these conditions, the findings primarily characterize the English-language segment of international scientific discourse, whereas specific research traditions developed within particular European and Asian academic communities may be underrepresented.

The structure of the publication dataset may also be affected by publication bias. The identified thematic configuration reflects not only prevailing research interests but also the conditions under which the academic publishing system operates, including editorial priorities and manuscript selection practices. Therefore, the predominance of publications reporting positive outcomes of digitalization should not be interpreted directly as evidence that this perspective dominates the entire body of research. Likewise, the frequency with which a particular term occurs should not be treated as an independent indicator of its theoretical or practical significance.

The interpretation of citation relationships should account for the unequal accumulation of citations over time. Earlier publications, all else being equal, have had more time to accumulate citations, which may lead newer research areas to occupy peripheral positions regardless of their substantive potential. The configuration of citation networks may also be influenced by self-citation, reciprocal citation within the same research group, and disciplinary differences in citation practices. Accordingly, the position of an author, institution, or thematic cluster within a citation network should be interpreted with due consideration of publication chronology and disciplinary context.

Specific limitations also apply to keyword co-occurrence analysis. The frequency of terms and the structure of their relationships reflect the organization of scientific discourse but do not directly characterize the actual state of the economic, marketing, social, or environmental processes under investigation. The results of such analysis depend on the parameters used to construct the network, including the minimum term-frequency threshold, the quality of synonym and spelling-variant normalization, and the selected clustering parameters. Changes in these settings may lead to differences in the number, boundaries, and composition of thematic clusters. Therefore, the resulting network configuration should be interpreted as an outcome of specific methodological procedures rather than as a definitive and unambiguous representation of the structure of the research field.

Taken together, these limitations define the boundaries within which the findings can be generalized. The analysis makes it possible to characterize trends, thematic structures, and relationships within the English-language body of publications indexed in Scopus; however, the results cannot be directly extrapolated to the entire global scientific literature or used to establish causal relationships between digitalization, marketing activities, and sustainable development outcomes.

Conclusions

The scientometric analysis of the research field at the intersection of marketing, digitalization and sustainable development demonstrates that this is a quantitatively mature but structurally fragmented area of scholarly inquiry. Publication activity increased exponentially, from 92 documents in 2020 to 1,006 in 2025, indicating a transition from an emerging interdisciplinary field to an actively developing research domain. The subject-area distribution is dominated by Business, Management and Accounting (1,975), Social Sciences (1,079), and Economics, Econometrics and Finance (1,042), whereas Environmental Science (514), Energy (359), and Agricultural and Biological Sciences (191) remain less represented. This indicates the predominance of a managerial and economic perspective and the insufficient integration of the natural-science and technical dimensions of sustainable development.

International collaboration is concentrated around the United Kingdom, India, Indonesia, Portugal, Spain and Ukraine, while Latin America, most African countries and the Middle East remain comparatively underrepresented. Institutional and co-authorship networks demonstrate a similar concentration around a limited number of universities and researchers, leaving many institutions and authors in peripheral positions.

The citation network has a polycentric but uneven structure. Its core encompasses strategic management, digital technologies, marketing and brand management, tourism, and sustainable development, while several peripheral clusters remain weakly integrated.

Overall, the findings demonstrate that the field is quantitatively mature but fragmented in content,

geography and research-community structure. The main research gap concerns the insufficient integration of marketing, technological and environmental dimensions, as well as the concentration of research within a limited group of authors, institutions and countries. Such a model should connect digital marketing practices—including personalization, communication automation and platform-based consumer interaction—with measurable environmental and social performance indicators. Its empirical validation could reduce the fragmentation of existing research and strengthen the conceptual and practical integration of digital marketing with ESG and sustainable development objectives.

Given the unevenness of the geographical structure of the international collaboration network, an important direction for further work is to conduct comparative cross-country studies covering regions that are insufficiently represented in the existing scientific discourse — primarily the countries of Latin America and Africa. Such studies would make it possible to verify whether the conclusions obtained predominantly on the basis of materials from the European and Asian scientific space (the United Kingdom, India, Indonesia, Portugal, Spain, Ukraine) are universal or are instead conditioned by the specific institutional and technological context of individual countries.

No less promising, given the relative isolation of applied clusters in the keyword network ("agriculture," "fashion industry," "smart tourism"), is the sectoral verification of the proposed models in sectors with heightened environmental sensitivity of production processes - the agricultural sector, the fashion industry, and tourism - including with regard to the latest technological platforms (the metaverse, the platform economy). This would make it possible to establish the limits of generalizability of the identified patterns and to reveal sectoral specificity in the implementation of sustainable digital marketing.

The implementation of the aforementioned directions requires a corresponding organizational precondition — the expansion of interdisciplinary and inter-institutional research infrastructure, since the identified fragmentation of the co-authorship network and the concentration of institutional collaboration around a limited circle of units constrain the potential for a comprehensive study of the problem area.

Finally, an independent avenue for further research is the study of the potential of social marketing as an instrument for achieving the Sustainable Development Goals in combination with digital communication channels - social networks and influencer marketing - which logically complements the proposed integrated model and expands the applied significance of the results obtained for the formation of public policy and corporate sustainable-development strategies.

Overall, the outlined prospects follow directly from the empirically identified structural disproportions of the scientific field and are consistent with the logic of sequential scholarly inquiry - from theoretical generalization, through the development of measurement tools, to empirical verification at the cross-country, sectoral and institutional levels - which creates a coherent program of further research at the intersection of marketing, digitalization and sustainable development.

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INTEGRATED STRATEGIC MANAGEMENT OF ENTERPRISE RESOURCE AND OPERATIONAL EFFICIENCY

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Abstract
Contemporary enterprises face market uncertainty, resource constraints, intensified competition, rapid digital transformation, and growing operational and financial risks. Under these conditions, isolated management of individual functional areas is increasingly insufficient, as decisions concerning logistics, marketing, finance, human resources, and taxation are interrelated and jointly influence resource use and business processes. The study therefore aims to substantiate an integrated approach to the s
trategic management of enterprise resource and operational efficiency and to determine the role of coordinated functional decisions in achieving higher efficiency. The theoretical framework combines the resource-based view, dynamic capabilities, strategic fit, and functional integration perspectives. Digitalization and risk management are treated as cross-cutting factors supporting coordination, information exchange, analytical capabilities, and managerial responsiveness rather than as autonomous components of the integrated management system. The empirical analysis uses panel data from publicly listed retail enterprises selected according to the availability and consistency of financial, operational, human resource, and digital disclosures. The methodology includes the formation and normalization of functional indicators, their aggregation into an Integrated Strategic Management Index, and the construction of a Resource and Operational Efficiency Index reflecting enterprises' ability to transform available resources into operating outcomes. Descriptive statistics, correlation analysis, and panel regression modelling are used to examine the relationship between managerial integration and enterprise efficiency, with alternative panel specifications applied to assess the robustness of the results. The findings reveal a positive and statistically significant relationship between the integration of functional managerial decisions and resource and operational efficiency, indicating that coordinated management provides a stronger basis for enterprise performance than isolated functional optimization. After managerial integration is taken into account, neither digitalization nor risk exposure demonstrates an independent statistically significant relationship with efficiency. This supports the interpretation of digitalization as an enabling mechanism for information connectivity, analytical support, and cross-functional coordination, while risk should be considered within the broader system of coordinated managerial decisions. The study highlights the practical importance of aligning logistics, digital marketing, budgeting, human resource management, and tax management within a unified strategic framework. The proposed approach can help enterprises identify functional imbalances, improve resource allocation and process coordination, strengthen managerial adaptability, and increase resource and operational efficiency under changing business conditions.
KEY WORDS: logistics activities, digital marketing, budgeting, human resource management, tax management, strategic management.
JEL classification: M10, M21, L81, C23

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Introduction

Enterprise performance increasingly depends on the coordination of functional decisions rather than on the isolated optimization of individual areas. Logistics structures material and information flows (Mentzer et al., 2001; Flynn et al., 2010; Gajda et al., 2025), marketing shapes demand and resource requirements, financial management translates these requirements into budgets and funding constraints (Lileikienė et al., 2024; Lileikienė & Martinkienė, 2023), and human resource management determines the capacity to execute them (Huselid, 1995; Giedraitis et al., 2024; Burinskienė & Daškevič, 2023). Digitalization and risk management cut across these functions by strengthening information support and controlling uncertainty. Yet the literature remains fragmented regarding the joint effect of such coordination on resource and operational efficiency.

The study tests hypothesis H1 that the integration of logistics, marketing, financial, and human resource decisions has a positive and statistically significant effect on resource and operational efficiency. Its purpose is to substantiate an integrated strategic management approach and determine the effect of coordinated decision-making on enterprise performance. The research object is strategic management of enterprise efficiency; the subject is the theoretical, methodological, and applied principles of cross-functional decision integration. The study develops an indicator framework and tests it using a balanced panel of retail enterprises, indicator normalization, correlation analysis, and panel econometric models. The contribution is a unified empirical representation of functional integration that distinguishes managerial coordination from the cross-cutting effects of digitalization and risk exposure.

Theoretical framework

Contemporary enterprise conditions are characterized by intensifying competition, resource constraints, demand instability, uncertainty, and the need to ensure both current performance and long-term competitiveness. Under these conditions, marketing, logistics, financial, human resource, and tax decisions cannot be considered autonomous, as changes in one functional area directly affect others. For example, marketing expansion increases requirements for inventory, procurement, transportation, financing, and staffing, while changes in

logistics may require adjustments to assortment, pricing, and financial policy. Resource and operational efficiency therefore requires an integrated strategic approach that coordinates goals, resources, functional decisions, and performance outcomes (Barney, 1991; Teece et al., 1997; Kaplan & Norton, 1992; Christopher, 2016).

The theoretical foundation of this approach is the resource-based view of the firm. Barney (1991) argues that sustainable competitive advantages depend on the effective use of valuable, rare, inimitable, and non-substitutable resources, while Prahalad and Hamel (1990) emphasize core competences as a basis for coordinated resource deployment and long-term competitiveness. Thus, resource efficiency should be understood not simply as minimizing resource consumption, but as the ability to form, allocate, combine, and use resources in accordance with strategic priorities. This is particularly important under resource scarcity, when efficiency depends on the quality of resource configuration rather than its absolute volume (Barney, 1991; Prahalad & Hamel, 1990; Bujáki & Vinogradov, 2024).

However, resources alone do not ensure high performance. In a dynamic environment, enterprises must be able to sense changes, seize opportunities, and reconfigure their resource base. Teece et al. (1997) associate competitive advantage with such dynamic capabilities. Strategic management should therefore ensure both efficient use of existing resources and their continuous alignment with current and prospective enterprise needs (Solomatina, 2025).

Logistics occupies a central position in this integrated system. Mentzer et al. (2001) define supply chain management as the coordination of business functions and processes within and across enterprises, while Christopher (2016) emphasizes the systemic coordination of material, information, and financial flows. Flynn et al. (2010) establish a positive relationship between supply chain integration and enterprise performance, and Li et al. (2006) demonstrate the contribution of supply chain practices to competitive advantage and organizational performance. Recent studies also highlight intermodal transport and logistics cost optimization (Bairam & Valackiene, 2025; Lingaitienė & Burinskienė, 2024). Procurement, inventory, transportation, and distribution should therefore be treated as interconnected elements of strategic decision-making.

Logistics is directly linked to marketing because demand, assortment, pricing, distribution channels, and service levels determine requirements for logistics processes. Kotler et al. (2022) emphasize the interdependence of market decisions, customer value, channels, pricing, and demand management, while Varadarajan (2010) considers marketing strategy an integral component of strategic decision-making. Marketing decisions affect supply, inventory, distribution capacity, and service quality, whereas logistics capabilities determine the feasibility of market strategies. Their coordination should therefore form a unified value-creation system linking demand, supply capabilities, operational capacity, and resources.

The interaction of marketing, digital, and financial decisions is also confirmed by Dranus et al. (2026), who demonstrate that digitalization and volatility of marketing expenditures influence the financial performance of insurance companies. This supports the view that marketing expenditures should be evaluated in connection with digital capabilities and financial outcomes rather than in isolation.

The financial component includes budgeting, cost control, financing, and tax decisions. Lileikienė et al. (2024) emphasize the role of advanced management and FinTech models in supporting innovative activity, while Lileikienė and Martinkienė (2023) identify challenges to financial stability during economic downturns. Financial management should therefore combine resource allocation, stability, and the capacity to support operational and strategic change (Vinogradov & Nagy, 2025). Budgeting consequently links the resource requirements of marketing, logistics, and human resources with available financial capacity.

Tax management should be integrated into this financial framework because tax decisions influence available resources, financial outcomes, and risk. Desai and Dharmapala (2009) demonstrate that corporate tax decisions have implications for firm value beyond the tax function itself. Tax management should therefore be aligned with budgeting, financial planning, financial stability, and overall strategy, particularly under uncertainty (Desai & Dharmapala, 2009; Lileikienė & Martinkienė, 2023).

Human capital is another essential component of integrated management. Huselid (1995) establishes the relationship between HR practices, productivity, employee turnover, and financial performance, while Becker et al. (1997) consider HR a potential source of shareholder value. Giedraitis et al. (2024) further highlight employee empowerment as a factor of organizational performance. HR decisions should therefore correspond to logistics and marketing requirements, financial capabilities, and strategic objectives.

Digitalization represents a cross-cutting mechanism rather than an autonomous functional subsystem, providing information support, monitoring, automation, and analytical capabilities. Lileikienė et al. (2024) associate advanced management and FinTech models with innovative activity. Digitalization therefore strengthens information availability, process visibility, analytical capacity, and managerial responsiveness across functional areas (Nedbálek, 2024).

Risk management should constitute another cross-cutting element. Demand uncertainty, resource constraints, supply disruptions, marketing expenditure volatility, and financial and HR risks can simultaneously affect several functional subsystems. Lileikienė and Martinkienė (2023) highlight financial stability challenges, while Dranus et al. (2026) demonstrate the relationship between marketing expenditure volatility and financial performance. Risk management should therefore accompany the formation, implementation, monitoring, and adjustment of major managerial decisions rather than operate as an isolated function.

The synthesis of the above theoretical propositions provides grounds for constructing a conceptual framework in which strategic management serves as the central mechanism for coordinating goals, resources,

functional decisions, risks, and outcomes. The corresponding logic of relationships is presented in Fig. 1.

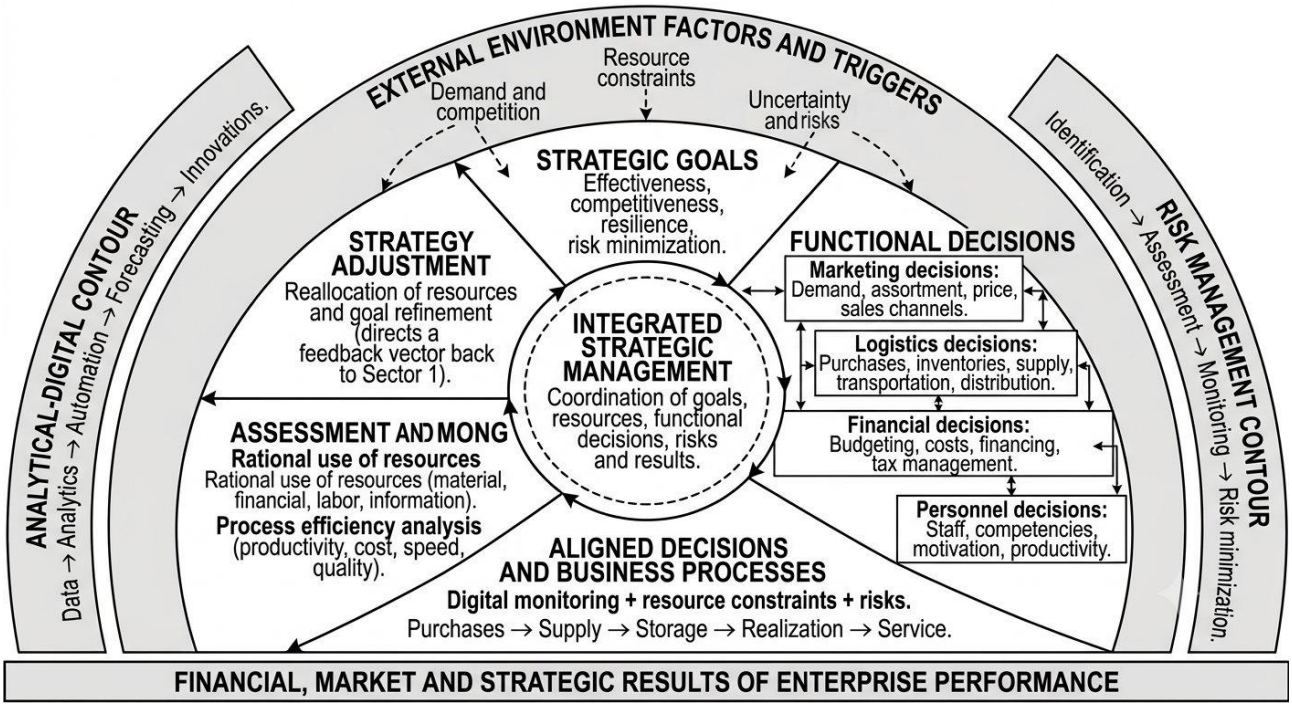


Fig. 1. Conceptual framework of integrated strategic management of enterprise resource and operational efficiency
Source: developed by the authors based on Barney (1991), Teece et al. (1997), Mentzer et al. (2001), Habánik et al. (2024), Giedraitis et al. (2025) and Dranus et al. (2026).

As shown in Fig. 1, the central element of the proposed concept is integrated strategic management, which aligns strategic goals, resources, functional decisions, and risks. The functional block combines marketing, logistics, financial, and HR decisions through direct and feedback relationships, ensuring the transformation of resources into business-process outcomes such as productivity, cost, speed, quality, and service level, and ultimately into financial, market, and strategic results.

A distinctive feature of the framework is the integration of an analytical-digital circuit and a risk circuit. Digitalization provides data collection and processing, automation, monitoring, forecasting, and analytical support across functional processes, while risk management enables the identification, assessment, monitoring, and mitigation of risks throughout decision-making (Bartekova et al., 2026). This is consistent with research emphasizing the role of digital and advanced management tools in supporting enterprise decisions and performance (Dranus et al., 2026; Lileikienė et al., 2024).

The framework incorporates feedback from performance outcomes to strategic goals and resource allocation, allowing the enterprise to assess goal attainment, adjust strategy, and reconfigure resources in response to environmental changes (Barney, 1991; Teece et al., 1997; Gruodė et al., 2025). In this context, resource efficiency refers to the rational formation, allocation, and use of material, financial, human, and information resources, whereas operational efficiency reflects their transformation within business processes through productivity, cost, speed, quality, and service level (Christopher, 2016; Flynn et al., 2010; Li et al., 2006).

Integrated strategic management is therefore defined as a system in which strategic goals guide the coordination of marketing, logistics, financial, and HR decisions; digitalization strengthens information and analytical capacity; risk management supports resilience; and performance feedback informs strategy adjustment and resource reallocation (Barney, 1991; Teece et al., 1997; Mentzer et al., 2001; Huselid, 1995; Ovchynnykova & Navickas, 2025).

The unresolved issue is the simultaneous quantitative assessment of these functional decisions within one framework while keeping digitalization and risk management analytically distinct. This gap motivates the operationalization of cross-functional integration and its empirical comparison with resource and operational efficiency (Neely et al., 1995; Hair et al., 2019; Calderon-Monge, & Ribeiro-Soriano, 2024).

Research Methods

The purpose of the study is to empirically examine whether the integration of logistics, marketing, financial, and human resource decisions contributes to higher resource and operational efficiency of retail enterprises. The study is based on the hypothesis that coordinated management of these functional areas generates a cumulative effect that cannot be adequately captured by examining individual functions separately. This approach is consistent with the resource-based view, which

emphasizes the importance of effectively organizing and utilizing resources to create competitive value (Barney, 1991; Shen et al., 2025).

The conceptual framework presented in Figure 1 defines integrated strategic management as a coordination mechanism linking marketing, logistics, finance, and human resources. Digitalization and risk management are treated as cross-cutting conditions affecting the effectiveness of integration rather than components of the integrated management index. This distinction separates internal functional integration from the technological and risk environment in which managerial decisions are implemented.

The empirical analysis covers 2021–2025 and focuses on nine publicly traded U.S. retail enterprises selected on the basis of complete financial, operational, human resource, and digital-sales disclosures. The balanced panel comprises 45 firm-year observations. Annual reports, SEC filings, and official corporate disclosures available through the investor-relations websites of American Eagle Outfitters, Best Buy, Gap Inc., Kohl's, Lands' End, Macy's, Oxford Industries, Sally Beauty Holdings, and Tilly's constitute the primary data sources (American Eagle Outfitters, n.d.; Best Buy, n.d.; Gap Inc., n.d.; Kohl's, n.d.; Lands' End, n.d.; Macy's, n.d.; Oxford Industries, n.d.; Sally Beauty Holdings, n.d.; Tilly's, n.d.). A panel-data design accounts for differences between enterprises and changes within enterprises over time (Wooldridge, 2001; Li et al., 2006).

Four functional blocks are used to operationalize integrated managerial decisions: marketing (M), logistics (L), finance (F), and human resources (HR). Each block is represented by an indicator reflecting the relationship between the resources employed and the corresponding economic result:

$$M_{it} = \frac{SG\&A_{it}}{Revenueit_{it}}, (1)$$

where $SG\&A_{it}$ (Selling, General and Administrative Expenses) - these are the company's selling, general and administrative expenses.

The marketing indicator captures the relative intensity of selling, general and administrative expenditure and serves as an observable proxy for the resource commitment associated with market-facing and supporting activities. The logistics indicator is defined as inventory turnover:

$$L_{it} = \frac{Cost\ of\ sales_{it}}{Average\ Inventory_{it}}, (2)$$

Inventory turnover is used as a proxy for the effectiveness of material flow management.

The financial block encompasses budgeting, financing, cost control, and tax management, which jointly determine the allocation of financial resources and the enterprise's capacity to support operational activities. Due to the absence of standardized publicly disclosed indicators that directly measure the quality of budgeting and tax management across the enterprises included in the sample, the empirical financial component is operationalized through the ratio of operating cash flow to total debt:

$$F_{it} = \frac{Operating\ Cash\ Flow_{it}}{Total\ Debt_{it}}, (3)$$

This indicator does not measure budgeting or tax management separately but serves as an observable proxy for the resulting financial capacity of the enterprise to generate operating cash flows relative to its debt obligations. Budgeting and tax management are therefore incorporated into the conceptual interpretation of the financial block rather than treated as independently measurable components of the index.

The human resource indicator is calculated as:

$$HR_{it} = \frac{Revenue_{it}}{Employees_{it}}, (4)$$

Because the indicators differ in measurement units and scales, min–max normalization is applied. For a stimulant indicator:

$$Z_{ijt} = \frac{X_{ijt} - X_j^{min}}{X_j^{max} - X_j^{min}}, (5)$$

where X_{ijt} represents the observed value of indicator j for enterprise i in period t, while and denote the minimum and maximum values of the respective indicator in the study sample.

For a destimulant indicator, the following transformation is applied:

$$Z_{ijt} = \frac{X_j^{max} - X_{ijt}}{X_j^{max} - X_j^{min}}, (6)$$

The normalized indicators are then aggregated into the Integrated Strategic Management Index (ISI):

$$ISI_{it} = \frac{M_{it} + L_{it} + F_{it} + HR_{it}}{4}, (7)$$

Equal weights are assigned to the four functional blocks to avoid subjective assumptions concerning their relative importance. ISI therefore measures the degree of integration of strategic managerial decisions rather than the efficiency of an individual functional area.

The dependent variable is the Resource and Operational Efficiency Index (REI), constructed independently from ISI. Three indicators are used:

$$RE_1 = \frac{Revenue}{Total\ Assets}, (8)$$

$$RE_2 = \frac{Operating\ Incom}{Revenue}, (9)$$

$$RE_3 = \frac{Operating\ Cash\ Flow}{Total\ Assets}, (10)$$

After normalization, the three indicators are aggregated as follows:

$$REI_{it} = \frac{RE_{1,it} + RE_{2,it} + RE_{3,it}}{3}, (11)$$

Thus, ISI and REI represent conceptually distinct constructs. ISI characterizes the integration of functional managerial decisions, whereas REI reflects efficiency in

asset utilization, operating income generation, and conversion of resources into operating cash flows.

Digitalization is included as a cross-cutting factor. Where comparable data are available, it is measured as the share of sales generated through digital channels:

$$DIG_{it} = \frac{\text{Digital Sales}_{it}}{\text{Revenue}_{it}}, \quad (12)$$

This indicator captures the observable contribution of digital sales to overall enterprise activity.

Risk exposure is measured by the ratio of total debt to total assets:

$$RISK_{it} = \frac{\text{Total Debt}_{it}}{\text{Total Assets}_{it}}, \quad (13)$$

Neither DIG nor RISK is included in the construction of ISI. This is intentional: digitalization and risk management are considered contextual and cross-functional factors that affect the conditions under which integrated managerial decisions generate efficiency outcomes.

To test the research hypothesis, the following baseline panel-data model is estimated:

$$REI_{it} = \beta_0 + \beta_1 ISI_{it} + \mu_i + \lambda_t + \varepsilon_{it}, \quad (14)$$

where REI_{it} - is the Resource and Operational Efficiency Index of enterprise i in period t;

ISI_{it} - is the Integrated Strategic Management Index;

β_0 - is the intercept;

β_1 - measures the effect of integrated strategic management on resource and operational efficiency;

μ_i - represents firm-specific effects;

λ_t - represents time effects;

ε_{it} - is the idiosyncratic error term.

The hypotheses are formulated as follows:

$$H0: \beta 1 \leq 0, \; H1: \beta 1 > 0, \quad (15)$$

The null hypothesis assumes that integration of logistics, marketing, financial, and human resource decisions does not have a positive statistically significant effect on resource and operational efficiency. The alternative hypothesis assumes a positive effect.

To assess the robustness of the estimated relationship, an extended specification is additionally considered:

$$REI_{it} = \beta_0 + \beta_1 ISI_{it} + \beta_2 DIG_{it} + \beta_3 RISK_{it} + \mu_i + \lambda_t + \varepsilon_{it}, \quad (16)$$

The empirical analysis compares pooled ordinary least squares (OLS), fixed-effects, and random-effects specifications. The choice between alternative panel estimators is based on the data structure and formal specification testing, including the Hausman test. Firm and time effects are considered to account for unobserved heterogeneity and common temporal shocks.

The statistical analysis includes descriptive statistics and correlation analysis. The estimated coefficients are additionally assessed for heteroskedasticity and serial correlation, with heteroskedasticity- and autocorrelation-robust standard errors applied where necessary.

Given the short time dimension of the panel, dynamic panel estimation is not treated as the default specification. GMM estimators are considered only if the empirical results indicate substantial persistence in REI or potential endogeneity of ISI. This approach avoids imposing an unsupported dynamic structure and is consistent with established principles of panel-data econometrics (Wooldridge, 2001).

Results and Discussion

The empirical analysis was conducted using a balanced panel dataset comprising 45 observations for nine publicly listed U.S. retail enterprises over the 2021–2025 fiscal years. The sample included Macy's, Inc., Kohl's Corporation, Best Buy Co., Inc., The Gap, Inc., American Eagle Outfitters, Inc., Sally Beauty Holdings, Inc., Oxford Industries, Inc., Tilly's, Inc., and Lands' End, Inc. The final sample was constructed according to two criteria: the availability of a complete set of financial and human resource indicators required to calculate the functional components of integrated strategic management, and the systematic disclosure of the share of sales generated through digital or online channels. This approach ensured the construction of a consistent dataset for calculating M, L, F, HR, ISI, REI, DIG, and RISK.

The DIG variable was measured as the share of sales generated through digital or e-commerce channels in the respective sales base reported by each enterprise. The definition of the digital channel consistently applied by each enterprise in its corporate reporting was used throughout the study period. This approach preserved the temporal comparability of the indicator within each enterprise and enabled digitalization to be incorporated into the empirical model as a cross-cutting control factor.

The descriptive statistics are presented in Table 1. The results indicate substantial heterogeneity among the enterprises in terms of their functional characteristics, the degree of integration of managerial decisions, digital penetration, and resource and operational efficiency.

Table 1. Descriptive statistics of the variables in the study sample

Variable	Mean	Standard deviation	Minimum	Maximum
M	0.351	0.095	0.165	0.553
L	4.054	1.529	1.770	6.930
F	0.258	0.207	−0.217	0.826
HR, USD thousand per employee	230.01	118.67	101.34	514.42

ISI	0.422	0.116	0.260	0.737
REI	0.571	0.171	0.400	1.067
DIG	0.345	0.160	0.072	0.763
RISK	0.427	0.115	0.225	0.682

Source: calculated by the authors based on publicly available corporate and financial reports of the enterprises included in the sample

The mean value of the marketing component M, measured as the ratio of SG&A expenses to revenue, was 0.351. Its variation from 0.165 to 0.553 reflects differences in the operating and administrative cost structures of the retail enterprises. The average inventory turnover indicator L was 4.054, while the difference between its minimum and maximum values indicates considerable heterogeneity in logistics models and the speed at which inventories are converted into sales.

The financial component F exhibited the greatest relative variability. Its mean value was 0.258, while the minimum value was negative. This reflects the presence of individual periods with negative operating cash flows and supports retaining such observations in the sample, as they capture actual changes in the financial position of the enterprises. The substantial variation in HR likewise demonstrates significant differences in the productivity of human resource utilization.

The Integrated Strategic Management Index ISI had a mean value of 0.422, ranging from 0.260 to 0.737. Thus, even among enterprises operating within the same broad sector, considerable differences can be observed in the configuration of marketing, logistics, financial, and human resource decisions. The mean value of the outcome variable REI was 0.571, further confirming differences in the ability of enterprises to transform available resources into operational outcomes.

The variation in DIG is particularly relevant to the analysis. The average share of digital sales was 34.5%, ranging from 7.2% to 76.3%. The sample therefore includes both enterprises for which digital channels constitute a supplementary component of the sales model and enterprises characterized by high digital penetration. This variation provides a sufficient empirical basis for examining whether digitalization has an independent effect on REI, or whether its effect is primarily manifested through the integration of functional managerial decisions.

The next stage involved a correlation analysis of the main variables. The results are presented in Table 2.

Table 2. Correlation matrix of the main variables

Variable	ISI	REI	DIG	RISK
ISI	1.000	**0.755**	0.197	−0.763
REI	**0.755**	1.000	0.145	−0.583
DIG	0.197	0.145	1.000	−0.637
RISK	−0.763	−0.583	−0.637	1.000

The strongest relationship was observed between ISI and REI, with a correlation coefficient of 0.755. This indicates that enterprises with a higher degree of integration of marketing, logistics, financial, and human resource decisions tend to exhibit higher resource and operational efficiency. However, correlation analysis reflects only the overall association and does not distinguish structural differences across enterprises from changes occurring within individual enterprises over time.

The correlation between DIG and REI was positive but weak, at 0.145. Thus, a higher share of digital sales alone does not exhibit a strong direct relationship with resource and operational efficiency. At the same time, the weak positive relationship between DIG and ISI ($r = 0.197$) indicates that digital penetration and the degree of functional management integration are related but distinct characteristics of an enterprise.

The RISK variable was negatively correlated with both ISI (−0.763) and REI (−0.583). This suggests that enterprises with higher debt burdens within the sample generally exhibit lower values of both the integrated strategic management index and resource and operational efficiency. Nevertheless, conclusions regarding the independent effect of RISK require multivariate estimation.

To directly test the research hypothesis, an extended panel model was estimated in which ISI served as the main explanatory variable, while DIG and RISK were included as control variables. Three specifications were estimated sequentially: Pooled OLS, the Fixed Effects model, and the Random Effects model. The results are presented in Table 3.

Table 3. Results of panel regression model estimation

Variable / statistic	Pooled OLS	Fixed Effects	Random Effects
ISI	**1.0885**	**0.7958**	**0.8482**
Standard error	0.3250	0.2099	0.1663
p-value	**0.0008**	**0.0002**	**<0.001**
DIG	−0.0241	−0.2747	−0.1139
Standard error	0.1494	0.2196	0.2139
p-value	0.8720	0.2110	0.5945
RISK	−0.0521	0.0170	0.0218
Standard error	0.3550	0.2033	0.2135
p-value	0.8833	0.9335	0.9187
R^2	0.5753	0.5115*	0.5168
Number of observations	45	45	45

** Within-R2 is reported for the Fixed Effects model.*

The results of all three specifications demonstrate a robust positive and statistically significant relationship between ISI and REI. In the Pooled OLS model, the coefficient on ISI was 1.0885 ($p = 0.0008$). After controlling for time-invariant enterprise-specific characteristics in the Fixed Effects model, the coefficient decreased to 0.7958 but remained positive and highly statistically significant ($p = 0.0002$). The Random Effects model produced a similar result, with $\beta_1 = 0.8482$ and $p < 0.001$.

The consistency of the direction and statistical significance of the ISI coefficient across all three specifications is particularly important. It indicates that the positive relationship between the integration of managerial decisions and resource and operational efficiency cannot be attributed exclusively to structural differences across enterprises. The Fixed Effects result shows that changes in the degree of managerial integration within enterprises over time are also positively associated with changes in resource and operational efficiency.

The Hausman test was applied to select between the Fixed Effects and Random Effects specifications:

$\chi^2(3) = 1.007$; $p = 0.799$.

Since $p > 0.05$, there is no statistical basis for rejecting the null hypothesis that the differences between the FE and RE estimates are not systematic. Accordingly, the Random Effects model is used as the preferred specification for the main econometric interpretation. In this model, the coefficient on ISI is:

$\beta_1 = 0.8482$; $p < 0.001$.

Given the hypotheses

$H_0: \beta_1 \leq 0$; $H_1: \beta_1 > 0$.

The null hypothesis is rejected, while hypothesis H1 receives empirical support. The results therefore indicate a positive and statistically significant effect of the integration of marketing, logistics, financial, and human resource decisions on the resource and operational efficiency of the retail enterprises included in the sample.

At the same time, the coefficient on DIG was not statistically significant in any of the three models. In the Random Effects specification, it was −0.1139 with $p = 0.5945$. Therefore, after controlling for the integration of managerial decisions and financial risk, the share of digital sales does not demonstrate a statistically significant independent effect on REI. This finding is important for interpreting the role of digitalization within the proposed conceptual framework. It supports the treatment of digitalization not as an isolated functional block whose effectiveness is automatically determined by the share of online sales, but rather as a cross-cutting factor that provides an informational and technological basis for coordinating functional managerial decisions.

A similar result was obtained for RISK. Despite its relatively strong negative pairwise correlation with REI, after simultaneously controlling for ISI and DIG, the coefficient on financial risk in the Random Effects model was only 0.0218 ($p = 0.9187$). Thus, within the study sample, the debt burden does not exhibit a statistically significant independent effect on resource and operational efficiency once the integrated nature of managerial decisions is taken into account.

Managerially, the findings imply that marketing decisions should reflect logistics capacity; inventory policies should correspond to demand and financial constraints; HR decisions should support process productivity; and financial policy should sustain operations without excessive risk exposure. Digitalization provides the informational connectivity required to coordinate these choices.

The insignificant direct effect of DIG indicates that digital sales penetration is not a self-sufficient measure of efficiency. Digital channels can entail additional fulfilment, infrastructure, last-mile logistics, returns, and customer-acquisition costs; their contribution therefore depends on integration with the enterprise's other business processes.

The results should nevertheless be interpreted in light of several limitations. The panel comprises nine large publicly listed retail enterprises over five fiscal years; therefore, the findings primarily characterize large companies with a sufficient level of information disclosure and should not be automatically generalized to small and medium-sized enterprises. In addition, DIG primarily captures the output dimension of digital presence through the share of digital sales and does not encompass all aspects of the digitalization of internal business processes. Further research may therefore extend the time and cross-sectional dimensions of the sample, incorporate lagged effects, and examine more specifically the combinations of functional decisions through which digital technologies translate into improvements in resource and operational efficiency.

Conclusions

The empirical results confirm the central regularity underlying the proposed framework: cross-functional integration is positively associated with resource and operational efficiency. Across 45 observations for nine publicly listed U.S. retail enterprises in 2021–2025, ISI and REI show a strong positive correlation ($r = 0.755$), while the ISI coefficient remains positive and statistically significant in pooled OLS (1.0885; $p = 0.0008$), fixed effects (0.7958; $p = 0.0002$), and random effects (0.8482; $p < 0.001$). The Hausman test ($\chi^2(3) = 1.007$; $p = 0.799$) supports the random-effects specification for the main interpretation. These estimates provide empirical support for H1 and indicate that the relationship persists after accounting for firm and time heterogeneity.

Digitalization and risk exposure do not replace the role of functional integration. Although digital sales penetration varies from 7.2% to 76.3% across the sample, DIG is not statistically significant in the preferred model ($\beta = -0.1139$; $p = 0.5945$). RISK is likewise insignificant after controlling for ISI and DIG ($\beta = 0.0218$; $p = 0.9187$), despite its negative pairwise correlation with REI ($r = -0.583$). The resulting regularity is that digitalization and risk management operate more plausibly as cross-cutting conditions of coordinated management than as autonomous determinants of efficiency.

The scientific contribution is the separation of three analytical dimensions within one model: functional integration represented by ISI, resource and operational outcomes represented by REI, and contextual conditions represented by DIG and RISK. This structure avoids embedding digitalization or risk directly in the integration index and allows their independent effects to be tested. For business practice, the findings support coordinated

decisions on demand generation, inventories, financing, and workforce productivity rather than isolated functional optimization. Digital initiatives should therefore be evaluated jointly with fulfilment capacity, inventory requirements, financing constraints, and labour productivity, while risk controls should accompany resource allocation and strategic adjustment.

The evidence is limited to nine large publicly listed retailers and five fiscal years, so the identified relationships should not be generalized automatically to smaller enterprises or other sectors. Further studies should expand the cross-sectional and time dimensions of the panel, test lagged effects, and complement digital sales penetration with indicators of internal process digitalization. Such extensions would clarify the channels through which digital technologies and coordinated functional decisions jointly translate into resource and operational efficiency.

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RELEVANCE AND RESILIENCE OF REGIONAL MUSEUMS: A SERVICE DEVELOPMENT MODEL FOR CROSS-SECTOR COOPERATION

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Abstract
This applied research addresses the issue of service quality and cross-sector cooperation at regional museums, analysing the case of the regional museums in Lithuania. The study aims to answer the question of how, based on an assessment of visitor behaviour and expectations, the services of regional museums can be systematically improved, thereby increasing their social, educational and cultural value.
The research problem is grounded in the empirical contradiction between the museum cultural and educational potential and its low profile, limited visitor engagement and underutilised service potential. The study assumes that targeted modelling of service quality and possible cooperation, supported by data and the principles of universal design, can become an effective tool for strengthening the activities of regional museums.
The study was conducted using a mixed-methodology approach: a quantitative questionnaire survey, semi-structured interviews and complex research methods (web monitoring, observation (guided tour) and the mystery shopper method) of Suvalkija region museums.
The research findings revealed systemic gaps in the development of regional museum services: limited digital visibility, insufficient tailoring of services to different target groups, a low level of interactivity. Based on the results obtained, an integrated model for improving the operations of a regional museums was developed, encompassing solutions for service content, accessibility, communication and partnerships.
The scientific and applied value of the study lies in the possibility of applying and adapting the proposed model in other regional museums seeking to systematically improve service quality, increase audience engagement and strengthen the role of museums in the region's cultural ecosystem.
Research question: How can evidence from visitor and stakeholder assessments of regional museum service quality be integrated into a systematic operational model that improves museum services through cross-sector cooperation?
Research objective: To develop an integrated model for improving the cross-sector cooperation of a regional museum by evaluating the quality of the museum services based on empirical data.
Hypotheses:
H1: The engagement and satisfaction of visitors to the regional museum depend significantly on the interactivity of services, digital visibility and clearly communicated accessibility.
H2: An integrated model of service quality, accessibility and communication solutions creates the conditions for a regional museum to increase the diversity of its audiences and become a sustainable centre for culture and education.
KEY WORDS: service development, regional museum, tourism resilience, cross-sector cooperation, quality of services.
JEL classification: L80, L14, O35, R58.

Introduction

Regional museums play a vital role in preserving and promoting cultural heritage, but the effectiveness of their operations increasingly depends on their ability to adapt to changing visitor needs, information consumption habits and the context of cultural tourism. In this context, regional museums face the challenges of systematically increasing the accessibility, visibility and visitor engagement of their services whilst maintaining their cultural and educational identity.

The research problem is based on the identified contradiction between the museum cultural and educational potential and its limited visibility, insufficient accessibility of services, and the fragmented application of solutions for improving operations. The current situation indicates that isolated initiatives focused on individual aspects of operations do not ensure a long-term impact on visitor behaviour and the museums' role within the region's cultural ecosystem.

The subject of this applied research is the system of service quality and at a regional museum, analysing the case of the museums in Suvalkija region, in Lithuania.

The aim of the study is to assess the quality and digital visibility of the museum services and, based on empirical data, to develop an integrated model for improving cross-sector cooperation of a regional museum. The study proposes and tests hypotheses regarding the impact of service interactivity on visitor engagement and the sustainability of museum operations.

The study was conducted using a mixed-methods approach, combining quantitative and qualitative research methods. Data were collected using an online questionnaire, semi-structured interviews, web monitoring, observation (guided tour) and the mystery shopper method. This methodological combination allowed for a comprehensive assessment of the museums' activities from the perspective of both visitors and stakeholders, and ensured the systematic nature of the research and the reliability of the results.

The paper aims to contribute to the improvement of regional museum activities by proposing a data-driven, systematic and transferable operational model that can be adapted to other regional museums, taking into account the specific nature of their activities and the structure of their audiences.

Literature Review: The Importance of Ensuring Quality in Museum Services and of Cross-Sector Cooperation

Museums are not merely exhibition halls for historical artefacts, but also open-air exhibits (sculpture parks, miniature parks, ethnographic villages, etc.); they are not only custodians of culture but also play a vital role in education and community engagement. By fostering cultural understanding and empathy, they promote social cohesion. According to Mendoza & Talavera (2025), Velasco-Muñoz et al. (2025), contemporary museums are increasingly viewed as dynamic organisations that play a significant role in public life, whose activities are assessed not only by visitor numbers but also by the quality of the services they provide, their ability to adapt to social changes and to build sustainable relationships with various stakeholder groups. ICM highlights that this transformation reflects a broader shift toward a public value-oriented paradigm, in which museums are expected to contribute to social cohesion, well-being and sustainable development (2026).

Within this context, the concepts of relevance and resilience have become central to museum discourse. Relevance refers to the ability of museums to remain meaningful and accessible to diverse audiences, while resilience denotes their capacity to adapt to external pressures such as financial constraints, technological and digital change and shifting visitor expectations (Chaitas et al., 2024; Nikolaou, 2024). These dimensions are increasingly viewed as interdependent and are strongly influenced by the quality of services provided and the extent of collaboration with external stakeholders.

One of the primary determinants of museum relevance is service quality (Yang & Ai, 2023). Contemporary studies suggest that museum service quality is multidimensional, encompassing visitor satisfaction, engagement, learning outcomes, and emotional impact (Dewi et al., 2026; Luo et al., 2026).

The strategic guidelines for 2022–2025 formulated by the American Alliance of Museums had emphasised that high-quality services are inseparable from the mission of museums – to contribute to public well-being, learning and cultural inclusion (American Alliance of Museums, 2021). Ensuring service quality in museums is understood as an ongoing process, encompassing the identification of visitor needs, adherence to professional standards, and the ability to respond to rapidly changing cultural and economic factors. It should be emphasised that museums must be flexible, capable of creating and applying innovative solutions, and operating as organisations grounded in human experience that actively build and maintain trust through collaboration with the public (Institute of Museum and Library Services, 2022).

Service quality is directly linked to museums' commitment to providing meaningful, ethical and professionally high-quality experiences. Research indicates that the assessment of the quality of museum operations is increasingly based on measurable indicators, such as: large-scale collaborative initiatives, the level of professionalism, expert competence and the ability to ensure consistent improvement of operations. This concept of professionalism in museums means that organisations must operate according to clear quality standards, continuously assess the effectiveness of their services and, where necessary, adjust their activities to meet public expectations and shift towards evidence-based management approaches that prioritise continuous improvement and responsiveness to audience needs (Yang & Ai, 2023; Pham et al., 2025; Yong et al., 2025). This indicates that museums must systematically evaluate their services in order to ensure high standards and remain competitive within the cultural sector.

At the organisational level, ensuring high service quality requires a broad set of competencies. Professionalism in the museum sector is no longer limited to curatorial expertise but includes skills related to communication, innovation and intercultural engagement (Del Vilar et al., 2025; Bas, 2023; Yang & Ai, 2023). These competencies are essential for addressing the needs of increasingly diverse audiences and for adapting to contemporary challenges such as digital transformation and changing patterns of cultural consumption.

Since museums are generally non-profit organisations, and for a long time their primary task has been to collect and preserve movable and immovable assets of enduring artistic, historical and cultural value, and to carry out educational and scientific work for the benefit of society, it is not surprising that most museums are funded from state budgets, by stakeholders seeking social investment, and from donations (Zmejevskienė, 2023).

At the same time, financial constraints remain a significant challenge for museums, particularly in contexts where public funding is declining (Sharp & Summers, 2025). Museums face increasing pressure to deliver high-quality services while operating with limited resources, highlighting the importance of efficiency and innovation for organisational sustainability (Mendoza & Talavera, 2025).

Recently, the cultural sector has been facing a decline in financial resources, which is particularly evident in Europe, where public investment in cultural services has been systematically decreasing. Such circumstances are prompting museums to seek new funding models and forms of partnership that would help to diversify revenue, engage a wider section of the public and create innovative service solutions. Cooperation with the business sector provides museums not only with financial support but also with strategic value, enabling them to implement projects requiring specialised expertise. Furthermore, museums are increasingly being integrated into urban development initiatives as part of the social infrastructure, contributing to the creation of a sustainable living environment (Chaitas et al., 2024).

In response to these challenges, cross-sector collaboration has emerged as a key strategy for enhancing both service quality and organisational resilience. Recent literature emphasises that collaboration with partners from sectors such as education, technology, health and creative industries allows museums to access new knowledge, resources and capabilities. Economic challenges are encouraging museums to collaborate more actively with organisations in the fields of culture, education, technology and social innovation, as such partnerships help to ensure the continuity and

sustainability of services, diversify funding, and strengthen the role of museums within the cultural ecosystem (Chaitas et al., 2024).

The evolution of contemporary museum activities clearly shows that collaboration with business organisations is becoming not merely an additional opportunity, but a strategic necessity for developing high-quality services and ensuring the institution's sustainability.

Partnerships are important not only for economic reasons – they also make a significant contribution to the fulfilment of museums' social mission. ICOM initiatives, such as the 'Outstanding Museum Practice Award', demonstrate that museums participating in collaborative networks are more likely to develop inclusive and socially responsible programmes that promote dialogue, cultural diversity, equality and community empowerment. These practices demonstrate that partnerships help museums not only to enhance the quality of their services but also to become active agents of social change, capable of responding to the needs of society (Cotter, 2025).

In recent years, the potential of unconventional forms of partnership has also been highlighted. A special issue of Museum International (2025) documents museum collaboration with the gaming, hospitality, health, cinema, real estate and environmental sectors – such intersections enable the creation of new service models, but at the same time require clear ethical guidelines and risk management (International Council of Museums, 2025). Communication and public relations practices also show that organisations are seeking meaningful and engaging experiences (Vázalová Gartnerová, 2025). A shift from 'repositories of artefacts' to events and night-time programmes based on stories, community and technology, which broaden the composition of the audience and the ways in which they participate (Doxanaki & Pappa, 2025).

The focus of collaboration between business organisations and museums is complemented by efforts to strengthen the cultural competence of the organisations' staff. Research on intercultural literacy in museums emphasises that the skills of educators and visitor services teams – flexibility, openness, facilitating dialogue, and dynamism – are critical to creating an engaging, evidence- and reflection-oriented visitor experience (Bas, 2023).

In summary, it can be said that the quality of museum services and collaboration are interrelated processes that determine a museum relevance and resilience. High-quality services create value for visitors, whilst sustainable partnerships enable museums to adapt, expand their activities and participate in broader cultural and social processes. In today's museum sector, these two aspects are no longer a choice but a necessity if museums are to remain relevant and valued by society.

Research methodology

The research problem is that regional museums increasingly seek to improve service quality and audience engagement, yet existing research rarely integrates visitor and stakeholder evidence into a systematic operational model based on cross-sector cooperation. This creates a gap in understanding how evidence-based service assessment can be translated into coordinated improvements in regional museum operations. The problem is based on an identified discrepancy between the content of the services provided by the museum and their perceived relevance to different target audiences, as well as between the declared accessibility and its actual visibility to visitors.

Research object: The system of service quality at regional museums (analysing the case of the Suvalkija region museums in Lithuania) and their potential for the cross-sector collaboration.

Research objective: To develop an integrated model for improving the cross-sector cooperation of a regional museum by evaluating the quality of the museum services based on empirical data. The following hypotheses are tested in the study:

H1: The engagement and satisfaction of visitors to the regional museum depend significantly on the interactivity of services, digital visibility and clearly communicated accessibility.

H2: An integrated model of service quality, accessibility and communication solutions creates the conditions for a regional museum to increase the diversity of its audiences and become a sustainable centre for culture and education.

Research methods and design: to achieve the research objective and test the hypotheses, a mixed-methods design was employed, combining quantitative and qualitative methods. This methodological approach allowed not only for the assessment of statistical trends but also for the exploration of deeper aspects of the perception, use and evaluation of services.

The study was conducted in three stages, ensuring data triangulation and the reliability of the results.

Stage I – quantitative research (questionnaire survey)

In the first stage, a quantitative study was conducted – an online questionnaire survey. The study population consisted of residents of Lithuania, from cities like Vilnius, Kaunas, Klaipėda, Šiauliai, Panevėžys, Marijampolė, Alytus and Prienai. The study sample comprised 417 respondents.

The questionnaire comprised 33 questions covering museum-visiting habits, evaluation of services, information dissemination channels and motivation to visit museums, especially in regions. The questionnaire included screening and leading questions, which allowed respondents to be categorised according to their experience with regional museums. Suvalkija region was not emphasized at this stage of the research.

The sample size was calculated using the Paniotto formula, applying a 5% margin of error and a 95% confidence interval (minimum sample size – 384). The survey link was distributed between December 2024 and January 2025, in compliance with personal data protection requirements.

Due to the use of convenience sampling, the demographic structure of the sample reflects digital accessibility and respondent reachability, resulting in a predominance of youth and working-age individuals. Due to the small absolute number of retirement-age respondents (N = 9, i.e., ~2.1%), this subgroup is

insufficient for a standalone statistical analysis or comparative hypothesis testing; therefore, when evaluating age-related factors, the data were aggregated into broader age categories.

The data obtained were processed using statistical analysis methods with the IBM SPSS, whilst graphical data visualisation was carried out using MS Excel. The results of the quantitative study were used to test hypothesis H1.

Stage II – qualitative research (semi-structured interviews with representatives of the business and tourism sectors)

In the second stage, a qualitative study was conducted using the semi-structured interview method. This method aimed to reveal the experiences, expectations and attitudes of representatives from the business and tourism sectors towards regional museums as partners in services and cooperation. At this stage, the study was conducted on a national scale, covering all regions of Lithuania rather than focusing solely on the Suvalkija region.

Two types of interviews were conducted – interviews with companies organising outbound events and interviews with experts in local and inbound tourism. During the first round of interviews, representatives from six companies were interviewed; the questionnaire consisted of seven questions. During the second round of interviews, four tourism experts were interviewed; the questionnaire consisted of six questions. The interviews took place remotely between December 2024 and January 2025. The interview recordings were transcribed and analysed using thematic analysis. The data from this stage were used to interpret hypothesis H2 and construct the model.

Stage III – complex research methods (web monitoring, observation (guided tour) and the mystery shopper method)

The Complex research methods (web monitoring, observation (guided tour) and the mystery shopper method) were applied in the third stage. The main focus was on Suvalkija region museums in Lithuania, analysing their service delivery process, structure, visitor engagement and accessibility elements. The focus on museums in Suvalkija region was motivated by their geographical distance from Lithuania's major urban centres (Vilnius, Kaunas, and Klaipėda), which face greater challenges in attracting visitors, increasing visibility, and ensuring long-term financial sustainability. Limited tourist flows and smaller local populations increase the importance of innovative development strategies and external partnerships for these museums. Consequently, cross-sectoral collaboration may play a particularly significant role in enhancing their attractiveness, competitiveness, and long-term financial sustainability. Furthermore, the findings derived from the observation of museums in Suvalkija region are not limited to this specific geographical context. This stage allowed for an assessment of the actual implementation of the service and a comparison with the stated service descriptions.

Research ethics. The principles of research ethics were adhered to throughout the study. Respondents and informants were guaranteed anonymity, and data was used only in aggregated form.

Research results

In analysing the current aspects and indicators of the regional museum activities, three studies were conducted: a quantitative study (questionnaire survey of respondents in Lithuania), a qualitative study (interviews with representatives of the business and tourism sectors) and complex research methods (web monitoring, observation during the guided tour and the mystery shopper method). Due to the limited scope of this article, the results of the third stage of the research are not discussed in detail. However, the findings of this study contributed to the development of the proposed model.

Results of stage I: Summary of the questionnaire survey

First, general data was analysed in order to gain a clear understanding of general trends in the museum market. One of the indicators for evaluating museum activities is visitor frequency. Table 1 below presents the relevant data.

Table 1. Frequency of museum visits (N=417)

Frequency of visits	Percentage
Several times a month	6%
Several times a year	39%
Once a year	22%
Rarely or not at all	33%

Based on the data, it is noted that the largest proportion consists of people who visit several times a year – this group accounts for 39%. This indicates that for most respondents, visits are not regular, but there is an interest, albeit not a strong one.

22% of respondents stated that they visit once a year. This group reinforces the trend of irregular visits and, together with the 'several times a year' category, constitutes a clear majority. This suggests that sporadic/occasional visits predominate over regular ones. The smallest proportion – just 6% – consists of respondents who visit several times a month. This indicates that there are very few regular, frequent visitors, so the loyal audience segment is weak or very narrow.

In summary, it can be said that infrequent or moderately frequent visits predominate, whilst the proportion of regular visitors is minimal. This may indicate a need to strengthen the motivation to visit more often, improve the attractiveness of the offering, or increase the dissemination of information about the activities or services provided.

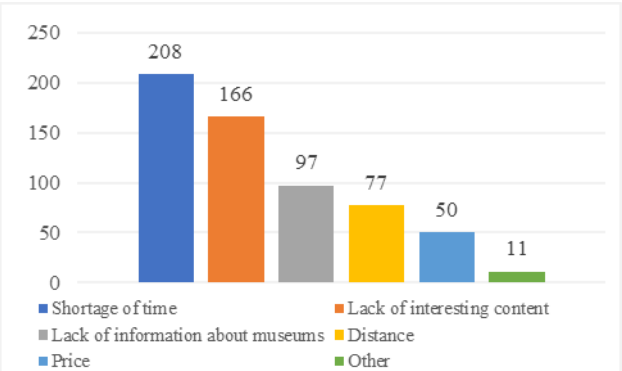


Fig. 1. Reasons for not visiting museums (N=417)

The respondents' answers reveal the most common obstacles of visiting museums: a lack of time, which was mentioned by as many as 208 people, who emphasised that their daily commitments prevent them from setting aside time for visits. Furthermore, as many as 97 respondents indicated that they lack information about museums' activities and events, which points to insufficient communication between museums and the public. These reasons help to explain why many people are not frequent visitors. To increase visitor numbers, museums could take greater account of visitors' needs by offering more interesting exhibitions and, most importantly, by disseminating information about their activities more actively, especially in social media.

It is noted that, in the respondents' opinion, the weekend is the best time to visit museums (79%), particularly Saturday (42%) – this is the most popular time for museum visits. On weekdays, visitor numbers are significantly lower, reaching up to 18%.

The next aspect examined is who visitors most often visit museums with.

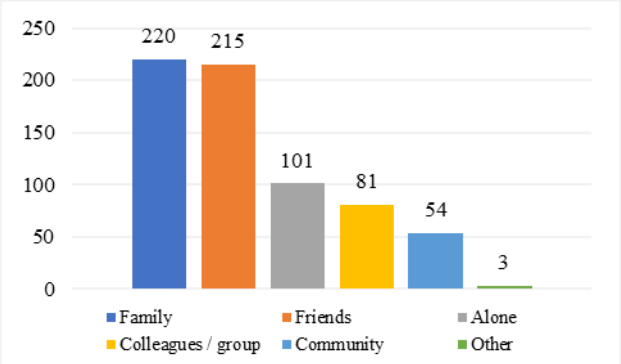


Fig. 2. Companions for museum visits (N=417)

Most people visit museums with their family (220 respondents) or friends (215 respondents), which reflects a very strong social and community aspect. Individual and group visits are less common, but still significant for certain visitor groups. These responses provide museums with an opportunity to tailor their offerings to different groups – families, groups of friends and individual visitors alike. It can also be observed that museums should do more to encourage group and community visits by organising special events or group activities.

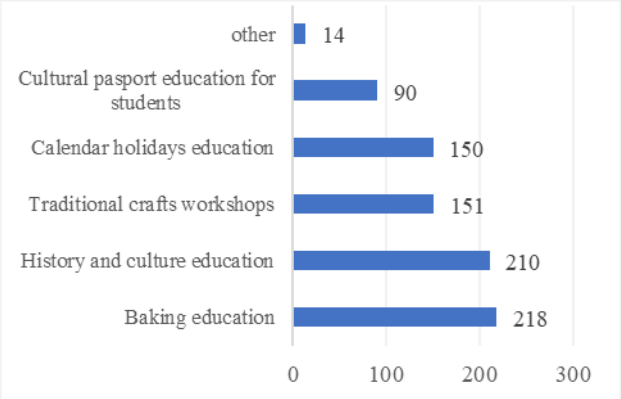


Fig. 3. Interest in educational, traditional, and ethnographic activities (N=417)

The data reveals that the main focus of interest in regional museums is on education through tradition and experience. Visitors most highly value activities that allow them to experience culture through practical participation; practical and culturally rich activities are most highly valued, and this forms a solid foundation for fostering ethnographic identity. By strategically strengthening these activities and integrating them even further not only into formal education but also into collaboration with other market participants (travel agencies, tourist information centres, business organisations), it is possible not only to increase visitor engagement but also to ensure the long-term continuity of traditions.

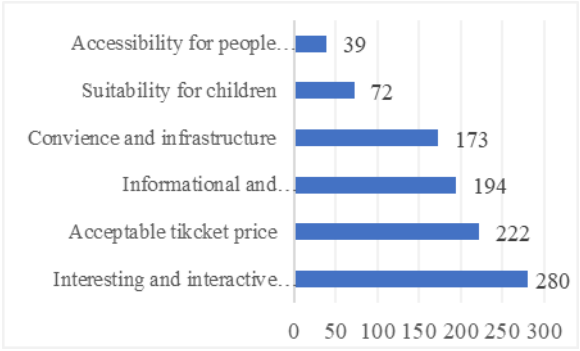


Fig. 4. Most important aspects when visiting a museum (N=417)

When visiting museums, respondents place the greatest emphasis on interesting and interactive exhibitions – these were mentioned by 29% of respondents. This indicates that visitors value the opportunity to engage directly with the exhibits, experience interactive activities and gain more information through various technologies that allow for a deeper understanding of the objects on display. Informative and educational value was important to 20% of respondents. This indicates that visitors wish not only to view the exhibits, but also to gain knowledge and experience that would be useful both in terms of learning and personal development. Museums are regarded not only as custodians of cultural heritage, but also as educational institutions. An affordable ticket price was important to 23% of respondents. This indicates that museum visits must be accessible to a broad section of the public, and that ticket prices can have a significant influence on people's decision to visit. This view may reflect concerns regarding accessibility and the economic ability to participate in cultural activities. Convenience and infrastructure were important to 17% of respondents. It is important to visitors that museums are convenient not only because of the exhibitions, but also because of various additional services, such as rest areas and toilets. This indicates that convenient facilities ensuring comfort are essential to guarantee a positive experience. Child-friendly facilities were important to 7% of respondents, whilst facilities for people with disabilities were important to 4% of respondents. This indicates that museums must be as accessible as possible to everyone, including families with children and people with special needs, to ensure equal access and inclusion.

The summary of the survey results shows that the most important factors for respondents are interesting and interactive exhibitions, as well as the informative and educational value that allows them to delve deeper into cultural heritage and learn. Affordable ticket prices and convenience are also important factors that influence people's decision to visit regional museums.

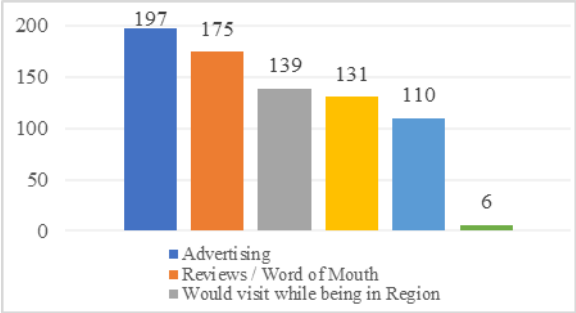


Fig. 5. Factors encouraging respondents to visit museums (N=417)

The survey data show that the reasons prompting people to visit the museums are advertising (197 votes), word of mouth (175 votes), a chance visit whilst in Region (139 votes), events (131 votes), and educational activities (110 votes).

When asked, "What is the regional museums lacking in order to attract more visitors?", 198 respondents felt that the museum needs more publicity, events, new exhibits and educational activities. A higher number of visitors would be achieved if themed exhibitions, cultural events and interactive displays were organised, engaging audiences of different ages and interests. The need for educational programmes was also highlighted: creative workshops, history lectures and themed tours could not only enrich the museum activities but also encourage visitor engagement and learning. These results indicate that regional museums have great potential to become a vibrant space for cultural and educational activities, which not only preserves heritage but also encourages community engagement and active participation.

When asked about the reasons that would encourage more frequent visits to regional museums in Lithuania, 217 respondents expressed their views, accounting for 52% of all survey participants. Among the suggestions mentioned were insufficient advertising and dissemination of information; many emphasised that there is a lack of attractive, easily noticeable advertising about museum activities, and that the use of social media or other modern means of communication is inadequate. Some even admitted that they were unaware of the existence of certain museums. Furthermore, a lack of time was frequently mentioned, as museums often operate during hours when most people are busy. Consequently, the suggestion to extend opening hours or better adapt to visitors' needs was one of the recurring ideas. Equally important is the fact that visitors are looking for interesting activities and exhibitions tailored to audiences of all ages. Interactive exhibitions, innovative presentations or the opportunity to get directly involved in activities were frequently highlighted as features that are lacking but highly desired. The importance of events and special offers was also highlighted. Many stated that they would visit museums more often if themed events, concerts or other special activities were held there. Free admission or special promotions were also mentioned as effective measures. Another important factor is recommendations from friends or acquaintances. Respondents acknowledged that they are more likely to choose a museum based on recommendations from friends and family or those spotted on social media. Finally, accessibility and infrastructure have a significant influence. Museums should be easily accessible, with clearly marked routes, convenient transport and free parking. Ticket prices also received considerable attention, with many citing them as too high, particularly when compared to the value received.

In summary, it can be said that to attract visitors, museums should place greater emphasis on advertising, innovative exhibitions, themed events and more visitor-friendly conditions. More flexible opening hours, more affordable prices and relevant activities would undoubtedly increase museum attendance.

Based on the survey data (N=417), the demographic structure of respondents is revealed. The largest proportion consists of working people (46.5%; N=194) and students (41.7%; N=174). A significant proportion is also made up of visitors without children (20.1%; N=84) and families with children (15.3%; N=64), which indicates a need to plan activities tailored to both families and individual visitors. A smaller proportion of respondents are unemployed individuals (5.5%; N=23) and pensioners (1.9%; N=8), the inclusion of these groups reveals opportunities for the museum to develop targeted initiatives, such as special events or pricing strategies.

Correlation and statistical association analysis of survey data

To examine associations among visitor characteristics, museum experiences, and behavioral outcomes, a correlation analysis was conducted using the quantitative survey dataset. Only statistically significant associations meeting the predefined effect-size threshold ($r_s \geq 0.25$) were retained for interpretation. Spearman's rank correlation coefficient (r_s) was applied to assess relationships between ordinal and numerical variables (Table 2).

Table 2. Statistically Significant Spearman Rank Correlations (r_s >= 0.300, p < 0.05) (N=417)

Variable 1	Variable 2	r_s	p-value	Statistical Interpretation
Staff helpfulness	Recommendation likelihood (NPS)	0.727	< 0.001	Strong positive: visitors who rated staff more positively were substantially more likely to recommend the museum.
Awareness of museum	Actual visit to museum	0.697	< 0.001	Strong positive: greater awareness was associated with actual museum visitation.
Age	Recommendation likelihood (NPS)	0.537	< 0.001	Moderate positive: older visitors reported higher recommendation intentions.
Ticket price rating	Staff helpfulness	0.413	< 0.001	Moderate positive: more favorable evaluations of staff helpfulness were associated with more positive ticket price perceptions.
Age	Staff helpfulness	0.311	0.008	Moderate positive: older visitors tended to evaluate staff helpfulness more positively.

The correlation analysis identified staff helpfulness, museum awareness, and visitor age as the factors most strongly associated with positive visitor outcomes. The strongest relationships were found between staff helpfulness and recommendation likelihood (r_s = 0.727) and between museum awareness and actual museum visitation (r_s = 0.697). Older visitors were more likely to recommend the museum and rate staff service positively. Additionally, favourable perceptions of staff helpfulness were associated with more positive evaluations of ticket prices, while museum visit frequency and awareness showed weaker but significant associations with recommendation likelihood.

Results of stage II: Summary of the interview analysis

The study conducted – comprising interviews with representatives of businesses and experts in local and inbound tourism – revealed key areas for improving the museum operations and untapped potential for collaboration. The research results show that the museum has a strong educational and cultural foundation; however, to achieve long-term sustainability and higher visitor numbers, it is essential to systematically develop partnerships with the tourism and business sectors.

Interviews with companies revealed that the most important criteria in organising team-building events are the needs, interests and motivation of employees. Events are most often perceived not only as entertainment, but also as a means of strengthening cooperation, improving mutual communication and creating a positive emotional atmosphere within the team. Most companies emphasise the importance of striking a balance between education, active pursuits and relaxation, so that the event is beneficial without being overloaded. The business sector is seeking experiential, interactive and engaging activities that combine education, an informal setting and leisure.

Off-site events are most often organised in natural surroundings or out-of-town locations, which allow participants to step away from their everyday working environment. Logistics, a comfortable setting, high-quality catering and the right timing are cited as essential conditions for a successful event. Although regional museums are not yet a common choice for such events, they are seen as having potential, particularly if the activities on offer were tailored to an adult audience, were more flexible in terms of group size and timing, and if the services included additional elements such as catering, creative workshops or unconventional spaces. This underlines the need for the museum to collaborate more actively with businesses and develop service packages tailored to them.

When considering museums as potential team-building venues, it emerged that some companies have already tried such events (e.g., at technical or history museums) and view them positively due to their educational value. Nevertheless, museums are not yet a natural choice – companies more often opt for the outdoors. However, the potential of museums is recognised if interactive, engaging activities tailored to an adult audience are offered, and conditions for informal interaction are created.

Tourism organisers emphasised that regional museums' appeal increases significantly when it is integrated into broader local tourism itineraries and service packages alongside other regional attractions, such as manor houses, catering establishments or natural sites.

According to tourism experts, the planning of tourist itineraries is based on travellers' needs, the type of group, thematic coherence, logistical convenience and value for money; therefore, elements such as the interactivity of the destination, professional guide services, infrastructure (toilets, catering, parking) and flexibility when working with groups are of particular importance. Logistics, infrastructure, flexibility of services, clear presentation of offers and smooth communication with tour operators are also cited as key factors determining the inclusion of the museum in tourism programmes.

Regarding museum awareness, experts frequently emphasised that individual sites become significantly more attractive when integrated into broader regional itineraries that combine cultural heritage with local dining and other points of interest.

Experts also emphasise the importance of communication – timely responses to enquiries, a clear description of services and active cooperation with tour operators are essential for the museums' successful integration into the tourism market. It is also noted that educational programmes are currently more focused on schoolchildren, resulting in a lack of clearly defined and attractive offers for adults.

To summarise the findings of the study, regional museums are inseparable from active cooperation with tourism companies, local businesses and institutions. The regional museum has the potential to become not just a single tourist attraction, but an integral part of the local tourism product – a stop-off point on routes, educational trails and themed tourism packages. Such a model of cooperation would increase the museum visibility, attract

new visitor groups, diversify revenue streams and strengthen the museum role in the region's cultural, social and economic development.

Results of hypothesis testing

Based on the results of the quantitative and qualitative research, an analysis of the proposed hypotheses was carried out and their validity assessed.

Results of the testing of Hypothesis H1

H1: The engagement and satisfaction of visitors to the regional museum depend significantly on the interactivity of services, digital visibility and clearly communicated accessibility.

The results of the quantitative study revealed that the most important elements of the museum experience for visitors are interactive exhibitions, informational and educational value, and the convenience of services. As many as 29% of respondents cited interactive and engaging exhibitions as the most important factor, whilst informational and educational value was significant for 20% of those surveyed. These figures confirm that visitor engagement is closely linked to the format in which content is presented and the level of interactivity.

The survey data also showed that the frequency of museum visits is low: only 6% of respondents visit museums several times a month, whilst as many as 33% visit rarely or not at all. One of the main reasons for this is a lack of information about museum activities, which was cited by 97 respondents. This confirms the importance of digital visibility and communication for visitor behaviour. In light of these results, hypothesis H1 is considered to be confirmed.

Results of the testing of Hypothesis H2

H2: An integrated model of service quality, accessibility and communication solutions creates the conditions for a regional museum to increase the diversity of its audiences and become a sustainable centre for culture and education.

The results of the qualitative research (interviews with business representatives and tourism experts) revealed that a museums' appeal increases significantly when it operates not as an isolated entity but as part of a broader system of services and experiences. Tourism experts emphasised that museums are more frequently included in itineraries when they offer clearly defined, themed, interactive solutions tailored to different audiences.

The interviews revealed that the business sector views museums as a potential space for team-building and experiential activities, but there is currently a lack of clearly structured offerings for adult audiences, flexibility in group sizes and complexity of services. This highlights the need to integrate educational, cultural, communication and partnership measures into a unified service development model.

Quantitative research data also confirms the potential for audience diversity: the museum is relevant not only to schoolchildren and families, but also to working people, students, business representatives and regional tourists. The factors cited by respondents as encouraging a visit to the museum (advertising, events, educational activities, recommendations) indicate that the systematic combination of these elements can have a long-term impact on visitor numbers.

Summarising the results of the quantitative and qualitative research, it can be stated that fragmented, isolated solutions (e.g. merely increasing advertising or merely improving infrastructure) are insufficient. Meanwhile, an integrated model of service quality, accessibility and communication creates the conditions for increasing the diversity of the museum audiences, strengthening its educational and social role, and ensuring the sustainability of its operations. In view of this, hypothesis H2 is considered to be confirmed.

Integrated operating model for a regional museum

The integrated regional museum operational model presented here is based on the results of scientific research and summarises the identified patterns regarding the structure of museum visitors, service quality, communication and operational improvement. The model reflects the relationships identified on the basis of empirical data between external environmental factors, regional museum strategic management decisions and the visitor experience.

The research findings revealed that regional museums visitors are characterised by social engagement, geographical diversity and varying expectations regarding museum services. These data support the need to plan museum activities systematically, integrating the dimensions of culture, tourism and services, rather than treating them as separate areas of activity.

The upper part of the model highlights the external environment, encompassing the regional context, the local community and tourism flows. The research data shows that a significant proportion of visitors come not only from the museums' region but also from Lithuania's major cities, particularly Vilnius; therefore, the museum activities must be oriented not only towards the local audience but also towards the national cultural tourism context. This allows the museum to be positioned as a regional attraction with the potential to operate within a broader cultural and tourism system.

The central axis of the model is strategic management, based on data-driven planning and decision-making. The study found that the dominant visitor groups are working people and students; therefore, strategic decisions must be geared towards the needs of these audiences, including the scheduling of activities, service formats and targeted communication. This part of the model emphasises that strategic management is not static but changes in response to shifts in visitor demographics and environmental factors.

The model identifies three interrelated functional areas: communication and marketing, service content, and accessibility. The research findings showed that visitor segmentation by age, social status and place of residence dictates the need to differentiate communication tools and service provision. The participation of families with children, individual visitors and groups of adults in the study underscores the importance of developing educational and experiential activities tailored to different segments. The dimension

of accessibility encompasses not only physical but also social and digital accessibility, which, according to the study's data, has a direct impact on the use of the museum services.

The results also revealed the regional museums' potential to develop a collaborative ecosystem. Considering the geographical origin of visitors and their travel motives, the integration of the museum into local and regional tourism routes, educational trails and comprehensive tourism packages becomes a key area of focus. Cooperation with tourism organisations and businesses for regional museums creates the conditions for attracting new visitor groups and increasing the use of the museum services.

The visitor/customer experience is central to the model and, according to the research findings, is directly linked to visitor satisfaction, loyalty and the museums' appeal. The inclusion of different demographic and social groups in the study suggests that a positive visitor experience must be created considering the diversity of audiences and individual needs.



Fig. 6. Integrated operational model for a regional museum

The novelty of the proposed model lies not in introducing cross-sector cooperation as a new concept, but in positioning it as a structural and functional component of regional museum service development. The ultimate outcome of the integrated regional museum operating model is regional cultural, social and economic added value, manifested in higher museum attendance, a broader audience and a stronger role for the museum within the region's cultural and tourism ecosystem. The model is transferable and can be adapted to other regional museums, taking into account their operational context and audience structure.

Conclusions

The applied research confirmed that the effectiveness of a regional museums' operations is determined by a complex interplay of service interactivity, digital visibility and clearly communicated accessibility, whilst isolated, fragmented solutions have no long-term impact on visitor engagement.

The research results showed that there is a contradiction between the positively rated visitor experience and the museums' low profile, leading to the conclusion that the main operational problem lies not in the content of the services, but in their accessibility and communication system.

The mixed-methods research data confirmed that the regional museums' audience is characterised by social and geographical diversity; therefore, the regional museums' activities must be planned on the basis of data-driven strategic management that integrates the needs of the audience.

The hypotheses tested during the study were confirmed, and an integrated model of regional museum operations was developed on this basis, summarising the relationships between the external environment, strategic management decisions, functional areas of activity and the visitor experience.

The model developed has methodological value and can be transferred and adapted to other regional museums, considering their operational context and audience structure.

Recommendations

Adopt an integrated approach to planning the activities of regional museums, in which service content, accessibility and communication are assessed as an interrelated system, and decisions are based on empirical visitor data.

Systematically apply audience segmentation and data-driven decision-making in museum strategic documents to ensure the relevance of services to different social and age groups.

Promote the integration of regional museums into local and regional tourism ecosystems, strengthening cross-sectoral cooperation as a long-term factor in increasing visitor numbers.

Use the developed integrated model of regional museum operations as a methodological basis for further applied research and practical solutions aimed at increasing the accessibility of cultural services and the social value of museums.

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MANAGING THE GREEN TRANSFORMATION OF LOGISTICS SYSTEMS THROUGH SUSTAINABLE FINANCE

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Abstract
The green transformation of logistics systems requires not only the introduction of low-carbon technologies, digital solutions, and circular economy principles, but also the coordination of financial, technological, and managerial decisions within an integrated system. The aim of this study is to develop an integrated management framework for sustainable finance supporting the green transformation of logistics systems in the European context. The methodological basis combines a structured search of scientific publications in Scopus, critical thematic analysis, examination of EU strategic, regulatory, and analytical documents, functional systematization of sustainable finance instruments, and conceptual synthesis of the findings. Five interrelated research approaches are identified: the finance–decarbonization approach; the ecosystem approach to sustainable supply chain finance and ESG; the resource–innovation and organizational–technological approach; the institutional–managerial and stakeholder approach; and the risk–resilience and integration approach. The study shows that current research provides substantial insights into individual aspects of green finance, green logistics, digitalization, ESG, and risk management, but does not yet offer a coherent management architecture linking financing with transformation targets, technological solutions, risks, and expected outcomes. Sustainable finance instruments are systematized according to their functional role in mobilizing long-term capital, financing technological and infrastructure modernization, reducing and sharing risks, supporting performance, and extending financial incentives across the supply chain. The principle of functional alignment is substantiated, according to which the financing structure should be determined with regard to the type of logistics asset, the scale of CAPEX, the payback period, projected cash flows, technological maturity, expected ESG effects, and the project risk profile. The key management mechanisms for integrating finance and green transformation are identified as strategic priority setting, project selection and assessment, financial structuring, stakeholder coordination, digital monitoring and ESG control, as well as risk, innovation, and digitalization management. On this basis, the Integrated Management Framework for Sustainable Finance and the Green Transformation of Logistics Systems is proposed. It combines the institutional and regulatory environment, sustainable finance instruments, management mechanisms, ESG criteria and risk management, green and digital transformation pathways, and transformation outcomes. An important element of the framework is the monitoring, learning and feedback mechanism, which enables the results achieved to be used to adjust investment priorities, the financing structure, and subsequent management decisions. The scientific novelty of the study lies in the shift from a fragmented analysis of individual financial and logistics instruments to a functional and managerial approach in which sustainable finance is considered an integral part of managing the trajectory of green transformation. The practical value of the proposed framework lies in its potential use by logistics companies to develop portfolios of transformation projects and select appropriate financing configurations; by financial institutions and investors to align capital allocation with technological maturity, ESG effects, and risks; and by public authorities to combine grant, guarantee, and private resources with priorities for the development of transport and logistics infrastructure.
KEY WORDS: sustainable finance, green logistics, green transformation, logistics systems, integrated management framework, ESG, circular economy.
JEL Classification: G32; L91; M10; Q56.

Introduction

The green transformation of logistics systems is increasingly moving beyond the greening of individual transport or warehousing operations. It involves changes in the principles of managing logistics infrastructure, flows, technologies, investments, and risks. For businesses and public institutions, the key challenge is not only to select environmentally sustainable technologies, but also to identify appropriate sources of financing, implementation mechanisms, and criteria for assessing performance. It is the interdependence of financial, technological, and managerial decisions that defines the contemporary transition towards low-carbon and resource-efficient logistics systems.

The scale of this challenge is particularly evident in the European Union. In 2023, transport, including international aviation and maritime transport, accounted for around 31% of total greenhouse gas emissions in the EU-27, while road transport was responsible for 72.9% of transport emissions (European Environment Agency, 2025). These figures cannot be directly equated with emissions from the logistics sector, but they reflect the carbon intensity of the transport base on which modern logistics systems depend. According to the Sustainable and Smart Mobility Strategy, the EU aims to reduce greenhouse gas emissions from transport by 90% by 2050. This objective is associated with the decarbonization of freight transport, the development of multimodality, digitalization, infrastructure modernization, and the mobilization of public and private investment (European Commission, 2020).

At the same time, the financing base for green transformation is expanding. According to the Climate Bonds Initiative, by the end of 2024, the cumulative volume of green, social, sustainability, and sustainability-linked debt instruments aligned with the Climate Bonds methodology had reached USD 5.7 trillion. In 2024 alone, approximately USD 1.05 trillion of such instruments were issued through 10,331 deals, representing a 31% increase compared with the previous

year (Climate Bonds Initiative, 2025). This indicates the gradual integration of sustainability criteria into capital allocation mechanisms. However, the scale of the sustainable finance market alone does not guarantee an effective transformation of logistics systems. What becomes decisive is the extent to which the characteristics of a financial instrument correspond to the type of logistics asset, the technological solution, the investment horizon, the risk profile, and the expected environmental and economic outcomes.

Scientific research confirms the need to consider the financial and logistics dimensions in close interrelation. Starostka-Patyk et al. (2024) proposed the Green Logistics Performance Index, which combines indicators of logistics and environmental performance and enables comparison of development trajectories across EU countries. Using panel data for 26 EU countries, Ozekenci and Nur (2025) found that green logistics and green finance contribute to reducing transport-related CO_2 emissions, confirming their complementary role in the decarbonization process. Dai et al. (2025), in turn, showed that the integration of green finance and the logistics industry has a positive effect on the green transformation of logistics, although this effect is nonlinear and characterized by substantial regional heterogeneity.

At the same time, the existing findings do not provide a comprehensive explanation of how financial resources should be integrated into the management system of green logistics transformation. Research on sustainable finance, green logistics, ESG, digitalization, decarbonization, and risk management has largely developed as separate streams. Financial instruments are often examined from the perspective of capital mobilization and environmental impact, while technological and logistics studies tend to focus on operational efficiency and emissions reduction. As a result, the management architecture linking financing, strategic management, green and digital technologies, ESG criteria, risks, and expected transformation outcomes remains less developed. In the European context, this challenge is further intensified by the need to take into account both common EU decarbonization and regulatory priorities and significant differences in the financial, technological, and infrastructure capacities of individual countries and regions.

The scientific contribution of this study lies in moving from a fragmented consideration of financial, managerial, technological, and environmental components towards their systematic integration within an Integrated Management Framework. Unlike approaches in which sustainable finance is viewed mainly as a source of capital for individual green projects, this study proposes treating it as an integral element in managing the trajectory of the green transformation of logistics systems. The practical value of this approach lies in the possibility of aligning financial decisions with technological priorities, management capabilities, risks, and expected economic and environmental outcomes.

The aim of the study is to develop an integrated management framework for sustainable finance supporting the green transformation of logistics systems in the European context. The framework combines sustainable finance instruments, management mechanisms, green and digital technologies, ESG criteria, risk management, and transformation outcomes. To achieve this aim, the following research questions are formulated:

RQ1. Which groups of sustainable finance instruments and which of their functions are most relevant to supporting the key areas of the green transformation of logistics systems?

RQ2. How can sustainable finance instruments be aligned with management mechanisms, green and digital technologies, ESG criteria, and the risk management system?

RQ3. What should be the structure and logic of relationships among the components of an integrated management framework for supporting the green transformation of logistics systems, taking into account the institutional characteristics of the European context?

Literature Review

The theoretical foundations of contemporary sustainable finance have developed at the intersection of the economics of externalities, the institutional approach, and the concept of sustainable development. The idea of correcting negative environmental externalities through economic instruments, together with the need to align the interests of economic actors through institutional mechanisms, created the basis for the gradual incorporation of environmental criteria into investment and financial decision-making (Pigou, 2013; Coase, 1960). In its contemporary interpretation, sustainable finance is no longer limited to financing individual environmental measures. It is increasingly viewed as a mechanism for directing capital towards low-carbon technologies, infrastructure modernization, changes in production and consumption patterns, and the structural transformation of economic systems.

The further development of this discussion makes it possible to distinguish a finance–decarbonization approach, within which green finance and green logistics are considered interrelated drivers of reduced environmental pressure. For EU countries, the development of green finance and green logistics practices has been associated with lower transport-related CO_2 emissions (Ozekenci & Nur, 2025). At the regional level, the integration of green finance and the logistics industry also has a positive impact on the green transformation of logistics; however, this relationship is nonlinear and depends on the level of regional development, the state of infrastructure, and the availability of financial resources (Dai et al., 2025). Global evidence further shows that the effects of supply chain logistics and green transportation are shaped by the financial environment, fluctuations in energy prices, and geopolitical risk (Kartal & Taşkın, 2026). The main strength of this approach lies in its ability to quantify the environmental outcomes of financial–logistics interactions. Its limitation is different: macroeconomic and regional models provide fairly convincing evidence as to whether green finance and green logistics contribute to

decarbonization, but they explain much less clearly how financial resources are transformed into managerial, technological, and infrastructure decisions.

The next stream can be defined as the ecosystem approach to sustainable supply chain finance and ESG. Unlike the previous approach, it shifts the focus from the macro level to the interaction among individual firms, financial institutions, and other participants in the supply chain. The systematization of research on supply chain finance, ESG, and value chains shows that financial decisions are increasingly viewed as part of value chain management rather than merely as a means of covering working capital shortages (Agrawal et al., 2024). A case-based approach to sustainable supply chain finance indicates that outcomes depend on the combination of financial incentives, digital technologies, and coordination among network participants (Zhou & Masi, 2025). Empirical studies also confirm the relationship between SCF and ESG: participation in supply chain finance can improve ESG performance by easing financial constraints and strengthening operational control (Wang et al., 2025), while supply chain synergy can serve as a channel for transmitting ESG effects across supply chain participants (Tian & Ye, 2026). A key strength of this approach is its attention to interorganizational relationships and the behavior of specific economic actors. At the same time, most such models remain focused on buyer–supplier relationships, working capital, access to finance, and ESG performance. As a result, long-term investment financing of transport, warehousing, energy, and digital logistics infrastructure is still insufficiently integrated into SSCF concepts.

A logical continuation of the ecosystem approach is the resource–innovation and organizational–technological approach. Within this perspective, financial resources are viewed not as an end result, but as one of the prerequisites for developing the technological and organizational capabilities of a firm. Research on the interaction among green finance, green logistics, and green technology confirms that the technological component can act as a mediating mechanism between financing, logistics practices, and green innovation (Wang et al., 2024). The development of digital supply chain finance extends this logic: digital platforms can reduce information asymmetry, ease financial constraints, improve disclosure, and support ESG performance (Gong et al., 2026). Blockchain performs a similar function by enhancing transparency, traceability, and interorganizational coordination, thereby strengthening the relationship among supply chain finance, green innovation, and ESG (Sun, 2026).

At the same time, technological solutions alone do not guarantee environmental performance. Tetteh et al. (2026) show that sustainable logistics practices generate results through a combination of operational, organizational, and human factors. Green transportation, sustainable waste management, green distribution and packaging, and green logistics information sharing can affect environmental performance both directly and through green competitive advantage, whereas the effect of green warehousing is mainly indirect. It is also important that green human resource management and energy efficiency alter the strength of particular relationships. Thus, the effectiveness of green transformation depends not only on technological modernization, but also on the ability of firms to develop appropriate competencies, human resource practices, and resource capabilities. The strength of this approach lies in identifying the specific channels through which financial resources can be translated into technological and organizational change. At the same time, digitalization, green innovation, and individual green logistics practices are often examined as separate drivers, mediators, or moderators, while their alignment with financial instruments, corporate strategy, risk management, and regulatory requirements remains less developed.

This gap leads to the institutional–managerial and stakeholder approach. Its starting point is that the green transformation of logistics is shaped not only by financial resources and technological capabilities, but also by the quality of the regulatory environment, organizational capacity for change, transparency, coordination, and the motivation of participants. The analysis of ESG barriers in the logistics sector shows that legal and compliance, institutional, and economic barriers may act as root causes of limited adaptation, while weak technological capabilities, low stakeholder engagement, or governance problems are often consequences of broader institutional constraints (Phan et al., 2025). At the level of logistics companies, it has been shown that combining green logistics practices, ESG disclosure, and government support can also have a positive impact on financial efficiency, highlighting the importance of interaction between the private and public sectors (Kim et al., 2024).

Recent studies on green logistics governance further broaden this perspective: institutional reforms can stimulate green innovation by strengthening the institutional framework and reconfiguring interorganizational networks (Zhang et al., 2026). The European dimension is particularly important for this study. Research on supply chain stakeholders in Europe shows that sustainability priorities are generally not in conflict at the regional level, but differ noticeably across stakeholder groups: infrastructure managers and academia place greater emphasis on environmental goals, operators and cargo owners focus more on economic and social aspects, while public authorities assign greater importance to governance (Castaño-Herrera et al., 2026). This means that the green transformation of logistics systems requires not only financing and technologies, but also mechanisms for reconciling different interests. A major strength of this approach is its recognition of the multi-actor nature of transformation. Its main limitation is that financing is still largely treated as one of several supporting factors rather than as a fully integrated element of the management architecture.

Another stream that has gained increasing attention in recent literature can be defined as the risk–resilience and integration approach. Its development reflects the need to account for uncertainty, supply chain disruptions, financial shocks, and possible trade-offs between environmental and economic outcomes. Studies of connectedness between supply bottlenecks and segments of green finance show that these relationships are nonlinear, asymmetric, and dependent on market conditions; consequently, the

financial system responds differently to logistics shocks under different market regimes (Yao et al., 2026). At the same time, green finance does not always produce uniformly positive outcomes. In high-carbon supply chains, environmental gains may be accompanied by short-term economic losses, crowding out of R&D, or lower resource allocation efficiency, which makes it necessary to consider environmental outcomes, economic efficiency, and resilience simultaneously (Gao et al., 2026).

In response to this complexity, integrated decision-support frameworks have emerged that simultaneously consider costs, emissions, service reliability, forecasting, transparency, and stakeholder coordination (Nagy et al., 2026). Such models bring research closer to the practical realities of managerial decision-making, but they still remain largely focused on operational optimization and selected types of risk. The full range of sustainable finance instruments, strategic management mechanisms, ESG criteria, and technological solutions is still only partially represented within a single architecture.

Overall, the development of research reflects a gradual shift from a narrow understanding of green finance as a source of financial resources towards its interpretation as part of a broader mechanism of technological, organizational, institutional, and managerial change. However, the different strands of this discussion have developed unevenly. Green finance studies provide stronger explanations of capital mobilization and allocation; green logistics research focuses more on the operational and environmental dimensions of transformation; SSCF examines the interaction of financing with buyer–supplier relationships and ESG; governance studies emphasize the role of regulation and stakeholders; digital research explores technological mechanisms of transparency, coordination, and innovation; and risk-oriented research addresses uncertainty and external shocks. The insufficient integration of these research streams remains a major conceptual gap in the current literature.

The critical review makes it possible to identify five interrelated research gaps. First, there is still limited understanding of how specific sustainable finance instruments should be aligned with different stages, assets, and pathways of the green transformation of logistics systems. Second, sustainable supply chain finance remains largely focused on working capital and interfirm relationships, while long-term financing of transport, warehousing, energy, and digital logistics infrastructure is much less integrated into these models. Third, ESG, digital technologies, green innovation, human capabilities, and risk management are often examined as separate drivers, mediators, or moderators, but are rarely brought together within a unified management architecture. Fourth, governance- and stakeholder-oriented models convincingly demonstrate the importance of institutional coordination, yet financial mechanisms generally remain a supporting rather than a fully integrated component. Fifth, even in the European context, existing studies tend to address either the macroeconomic relationship between green finance and green logistics or selected aspects of governance and stakeholder priorities, without developing a comprehensive framework that simultaneously integrates sustainable finance instruments, management mechanisms, green and digital technologies, ESG criteria, risk management, and transformation outcomes.

Thus, further development of this research area requires a shift from the analysis of separate financial, technological, or managerial instruments towards their systematic integration. This provides the conceptual basis for an integrated management framework in which sustainable finance is treated not as an external source of resources, but as an integral component of managing the trajectory of the green transformation of logistics systems.

Methodology and Research Methods

The research methodology reflects the conceptual nature of the study and is aimed at developing an integrated management framework for sustainable finance supporting the green transformation of logistics systems. The research design combines a structured review of the scientific literature, analysis of strategic and regulatory documents, thematic systematization of research approaches, grouping of sustainable finance instruments according to their functional purpose, and synthesis of the results obtained. This sequence makes it possible to consider financial, technological, managerial, and environmental components not in isolation, but as interrelated elements of the green transformation of logistics systems.

At the first stage, the scientific and information base of the study was developed. Relevant publications were searched in the Scopus database across four thematic areas: the relationship between sustainable/green finance and green and sustainable logistics; the integration of sustainable finance with logistics and supply chains; sustainable supply chain finance, green supply chain finance, and ESG; and green/sustainable logistics in the context of management frameworks, integrated management, governance, and strategic management. The main time horizon covered 2023–2026, with priority given to publications from 2025–2026. Earlier studies were used selectively as a theoretical basis for examining the evolution of sustainable finance and the institutional foundations of environmental transformation.

The analysis included mainly English-language research articles and review papers directly related to the research topic. The main selection criteria were the examination of the impact of green finance on decarbonization and green transformation; sustainable supply chain finance mechanisms; the role of ESG and governance in logistics and supply chain systems; the use of green and digital technologies; financial and non-financial risks; stakeholder interaction; management models; and integrated frameworks. Publications in which green finance or logistics were mentioned only marginally and had no direct relevance to the logic of the study were excluded from further analysis.

At the second stage, a critical thematic analysis of the selected literature was conducted. The studies were systematized into five conceptual approaches: the finance–decarbonization approach; the ecosystem approach to sustainable supply chain finance and ESG; the resource–

innovation and organizational–technological approach; the institutional–managerial and stakeholder approach; and the risk–resilience and integration approach. For each approach, its content, main focus, strengths, and limitations were identified. This made it possible not only to summarize current research directions, but also to identify issues that remain insufficiently explored.

At the third stage, strategic, regulatory, and analytical documents were examined. The information base for this stage included materials from the European Commission, the European Environment Agency, the Climate Bonds Initiative, and other international institutions relevant to the European context of transport decarbonization, sustainable finance development, and the green modernization of infrastructure. Their analysis made it possible to relate the findings of the scientific literature to current institutional and regulatory priorities of the European Union.

At the fourth stage, a functional systematization of sustainable finance instruments was carried out. The instruments were analysed not only by their form of financing, but also by their role in the green transformation process: mobilizing long-term capital; financing technological and infrastructure modernization; reducing and sharing investment risks; encouraging ESG-oriented decisions; and supporting innovative and digital technologies. This approach makes it possible to move beyond a simple list of green bonds, green loans, guarantees, or sustainability-linked instruments and to determine their place and functions within the management system of the green transformation of logistics.

At the final stage, the findings were conceptually synthesized. The analysis covered the relationships among institutional conditions, sustainable finance instruments, management mechanisms, green and digital technologies, risks, and expected transformation outcomes. On this basis, the Integrated Management Framework was developed.

The logic of the proposed framework is based on the alignment between financial instruments, financing objects, management mechanisms, technological solutions, risks, and expected economic and environmental outcomes. At the same time, the framework is conceptual in nature and is not intended to serve as a universal causal model statistically validated for all European countries. Its purpose is to systematize the main relationships and provide a basis for subsequent empirical testing.

To strengthen the validity of the conclusions, the results of the scientific literature analysis were compared with EU strategic and regulatory documents and analytical materials from international organizations. This made it possible to assess the extent to which the developed propositions correspond to current trends in sustainable finance, green logistics, and European decarbonization policy.

The overall sequence of the study, the methodological procedures applied, and the main results of each stage are summarized in Table 1.

Specialized software for bibliometric analysis was not used, as the study did not involve the construction of citation networks, co-authorship maps, or bibliometric mapping of the research field. Scopus was used as an information retrieval database, while the subsequent systematization and synthesis were based on the content analysis of the selected publications and documents.

Table 1. Logic of the Methodological Design of the Study

Stage	Methodological procedure	Main outcome
1	Structured search of publications in Scopus	Formation of an up-to-date body of scientific literature
2	Critical thematic analysis	Systematization of five conceptual approaches and identification of research gaps
3	Analysis of strategic and regulatory documents	Identification of the European institutional and regulatory context
4	Functional systematization	Grouping of sustainable finance instruments according to their role in the transformation process
5	Conceptual synthesis	Development of the Integrated Management Framework

Source: compiled by the authors.

Thus, the selected methodology provides a consistent transition from the analysis of current scientific research and the European regulatory context to the systematization of financial and management instruments. The results obtained provide a methodological basis for developing and substantiating the Integrated Management Framework presented in the following section.

Results and Discussion

The results of the study show that financing the green transformation of logistics systems is not simply a matter of expanding the range of available financial instruments. What is crucial is their alignment with the characteristics of a specific transformation project. Logistics assets differ substantially in terms of capital intensity, payback periods, technological maturity, cash flow structure, expected environmental effects, and risk levels. Therefore, a financing structure suitable for the modernization of a warehouse or vehicle fleet cannot automatically be applied to an intermodal terminal, charging/refuelling infrastructure, a large-scale digital platform, or supply chain transformation.

The European institutional environment provides a basis for such a differentiated approach. The EU Taxonomy establishes criteria for identifying environmentally sustainable economic activities; the European Green Bond Standard regulates the use of the European Green Bond designation and the related disclosure requirements; the Connecting Europe Facility and InvestEU provide mechanisms to support investment, while the Alternative Fuels Infrastructure Regulation sets requirements for the development of alternative fuels infrastructure. The Corporate Sustainability Reporting Directive, in turn, strengthens the importance of reliable ESG information for assessing

investment decisions and transformation outcomes (European Parliament and Council, 2020; 2021a; 2021b; 2022; 2023a; 2023b). CEF Transport has a budget of approximately EUR 25.8 billion for 2021–2027 and supports, among other areas, the development of TEN-T, cross-border connections, innovation, energy efficiency, and the reduction of the environmental impact of transport (European Commission, 2021b).

The research findings are presented in line with the three research questions formulated in the study. First, the functional role of sustainable finance instruments is identified; second, the management mechanisms for their integration are examined; and finally, these components are combined within the Integrated Management Framework.

Sustainable Finance Instruments and Functional Alignment

In response to RQ1, sustainable finance instruments were systematized not only by their form of financing, but primarily by the functions they can perform in the green transformation of logistics systems. This approach changes the logic of selection: from identifying an available source of funds to determining the financial solution that best matches the type of asset, the investment horizon, the expected ESG effect, and the risk profile. The main groups of instruments, their functional purpose, potential areas of application, and key management conditions are summarized in Table 2.

Table 2. Sustainable Finance Instruments for the Green Transformation of Logistics Systems

Group of instruments	Main instruments	Function in the transformation process	Potential areas of application in logistics	Key management conditions
Targeted debt instruments	Green bonds, European Green Bonds, sustainability bonds	Mobilization of long-term capital for environmentally oriented assets and projects	Intermodal terminals, energy-efficient warehouses, charging infrastructure, modernization of transport assets	Compliance with eligibility criteria, transparent use of proceeds, verification of environmental effects
Performance-linked financing	Sustainability-linked bonds, sustainability-linked loans	Linking financing terms to the achievement of defined sustainability targets	Emissions reduction, improved energy efficiency, fleet renewal, ESG programmes	Well-defined KPIs and baseline, regular monitoring, reliability of reported results
Bank and leasing finance	Green loans, investment loans, green leasing	Financing of specific assets and technological modernization	Low-carbon transport, warehouse equipment, energy installations, digital systems	Creditworthiness, predictability of cash flows, alignment of the financing term with the asset life cycle
Public and EU financing	Grants, CEF, AFIF, other targeted EU programmes	Support for infrastructure projects with high initial costs and significant public benefits	TEN-T, multimodal hubs, railways, ports, charging/refuelling infrastructure, digitalization	Alignment with programme priorities, co-financing, transparency of project selection and implementation
Risk-sharing and blended finance instruments	Guarantees, InvestEU-supported instruments, public-private risk sharing, insurance	Risk reduction and enhancement of project investment attractiveness	New technologies, alternative fuels, innovative infrastructure, projects with long payback periods	Sound risk allocation, additionality of public support, control of financial commitments
Sustainable supply chain finance	Sustainable SCF, digital SCF, ESG-linked supplier finance	Extension of financial incentives for green transformation across supply chain participants	Supplier decarbonization, sustainable packaging, reverse logistics, traceability	Quality of ESG data, information interoperability, accessibility for SMEs
Investment funds and equity instruments	Green investment funds, infrastructure funds, private equity	Scaling up innovative technologies and new business models	Green logistics start-ups, digital platforms, circular logistics, innovative infrastructure	Investment readiness, a viable business model, risk control, and an exit strategy

Source: proposed and compiled by the authors based on (European Commission, 2021a; 2021b; European Parliament and Council, 2020; 2021a; 2021b; 2023a; 2023b; Climate Bonds Initiative, 2025; Zhou & Masi, 2025).

As shown in Table 2, the different groups of financial instruments perform different functions and therefore cannot be considered interchangeable. Targeted debt instruments are primarily intended to mobilize long-term capital; loans and leasing are more suitable for financing specific assets; and public and blended finance can support infrastructure or innovation projects with significant positive externalities or higher levels of risk. Sustainable supply chain finance has a different functional focus, as it enables transformation

incentives to extend beyond an individual company to suppliers and other participants in the value chain.

This finding broadens the existing understanding of SSCF. Zhou and Masi (2025) emphasize the role of digital technologies, financial incentives, and stakeholder engagement in sustainable supply chain finance, while Agrawal et al. (2024) link SCF, ESG, and value chain management. The proposed systematization complements these approaches by incorporating long-term investment financing for logistics infrastructure, public and EU funding, and risk-sharing mechanisms, thereby extending beyond the predominant focus on interfirm relationships and working capital financing.

On this basis, the principle of functional alignment is formulated: the financing structure should be determined after assessing the transformation object, required CAPEX, payback period, projected cash flows, technological maturity, ESG effects, alignment with the EU Taxonomy, and the level of risk. The relationship among these components is presented in Figure 1.

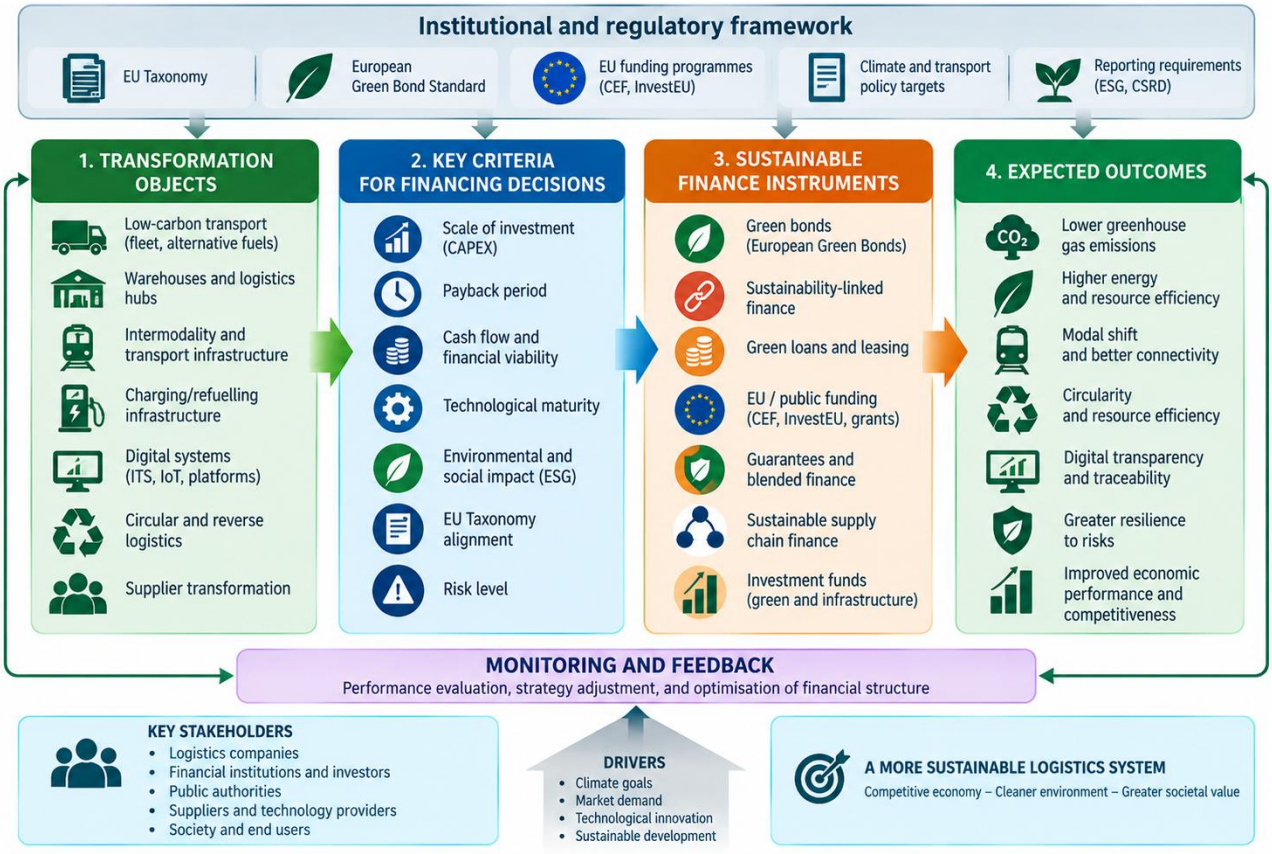


Figure 1. Functional alignment of financing with the green transformation of logistics systems

Source: developed by the authors based on the results of their own research (Dzwigol et al., 2021; Khaustova et al., 2022; Liashenko, Khaustova and Trushkina, 2022; Lileikiene et al., 2024; Ovchynnykova, Martinkienė and Navickas, 2024).

As shown in Figure 1, a separate set of financial decision-making criteria is positioned between the object of green transformation and the choice of a financial instrument. Financing is selected not simply because an instrument falls within the "green" category, but according to the economic, technological, environmental, and risk characteristics of the project. The institutional and regulatory environment defines the external conditions for this choice, while the involvement of key stakeholders and the influence of external factors shape the practical possibilities for its implementation.

Monitoring and feedback play a separate role in Figure 1. The assessment of achieved results makes it possible to review the financing structure, adjust investment priorities, and refine subsequent decisions. Thus, Figure 1 is not merely a classification scheme, but a model for substantiating financial decisions within the green transformation of a logistics system.

This approach is consistent with the current logic of transition finance in the EU, according to which the financial system should support not only activities that already meet sustainability criteria, but also credible transition pathways for companies and assets moving towards more sustainable models of operation (European Commission, 2020; 2021a).

Management Mechanisms for Integrating Finance and Logistics Transformation

Matching a financial instrument to the characteristics of a project is a necessary, but not sufficient, condition for an effective transformation. This defines the logic of RQ2: the financial decision should be embedded in a system of strategic planning, project selection, stakeholder coordination, performance monitoring, innovation management, and risk management.

Empirical studies confirm that the outcomes of green finance depend on the environment in which it is applied. For 26 EU countries, Ozekenci and Nur (2025) identified a relationship between green finance and green logistics and the reduction of transport-related CO_2 emissions. Dai et al. (2025) found a positive but nonlinear effect of the integration of green finance and the logistics industry on the green transformation of logistics, together with substantial regional heterogeneity in this effect. Thus, the availability of financial resources alone does not determine the outcome; what matters is the conditions under which these resources are translated into technological, organizational, and infrastructure changes.

This is also supported by firm-level studies. Wang et al. (2024) identified an interrelationship among green logistics, green finance, and green technology in fostering green innovation. Tetteh et al. (2026), in turn, showed that environmental performance depends not only on the implementation of sustainable logistics practices, but also on green competitive advantage, energy efficiency, and green human resource management. Therefore, financing should be considered together with the managerial, technological, and human resource capabilities of the firm.

The main mechanisms of such integration are systematized in Table 3.

Table 3. Management Mechanisms for Integrating Sustainable Finance and the Green Transformation of Logistic System

Management mechanism	Main content	Key participants	Expected outcome
Strategic priority setting	Definition of transformation goals, selection of priority assets, and sequencing of investments	Logistics companies, public authorities, infrastructure managers	Alignment of investments with long-term strategy
Project selection and assessment	Assessment of technical, financial, and environmental feasibility, EU Taxonomy alignment, and ESG criteria	Companies, banks, investors, public authorities	Development of a well-founded project portfolio
Financial structuring	Selection of a financial instrument or combination of instruments, financing terms, cost of capital, co-financing arrangements, and risk-sharing mechanisms	Project owners, banks, investors, financial institutions	Financial viability and bankability
Implementation coordination	Allocation of responsibilities, procurement, stakeholder coordination, and management of timelines and resources	Project owners, suppliers, authorities, technology providers	Coordinated actions and timely implementation
Digital monitoring and ESG control	Monitoring of emissions, energy use, logistics performance, financial KPIs, and sustainability indicators	Companies, financial institutions, auditors, regulators	Transparency in the use of funds and verification of results
Risk management and adjustment	Identification of financial, technological, regulatory, climate, logistics, and greenwashing risks; adjustment of project parameters	All key participants	Greater adaptability, reduced losses, and enhanced resilience
Innovation and digitalization management	Alignment of technological investments with the financing structure and transformation objectives	Logistics companies, technology providers, investors	Faster technological modernization and scaling of solutions

Source: proposed and compiled by the authors based on (Wang et al., 2024; Tetteh et al., 2026; Castaño-Herrera et al., 2026; Yao et al., 2026; Nagy et al., 2026).

An important element of Table 3 is stakeholder coordination. Castaño-Herrera et al. (2026) found that sustainability priorities are generally similar across European regions, but differ noticeably among stakeholder groups: infrastructure managers and the academic community place greater emphasis on environmental goals, cargo owners and operators focus more on economic and social aspects, while public authorities give greater priority to governance. Thus, even a financially viable and technologically well-founded project may face implementation challenges if the interests of its participants are not sufficiently aligned.

Equally important is continuous risk management throughout the transformation process. Yao et al. (2026) show that the relationship between supply chain bottlenecks and green finance markets is nonlinear, asymmetric, and dependent on market conditions. Gao et al. (2026) identify another dimension of the problem: positive environmental outcomes of green finance policies may be accompanied by short-term economic losses and constraints on innovation activity. Therefore, the assessment of transformation projects should take into account not only environmental performance, but also financial sustainability, innovation capacity, and resilience.

Integrated Management Framework for Sustainable Finance and Green Logistics Transformation

The functional systematization of financial instruments and the identification of management mechanisms for their application provided the basis for answering RQ3 and for developing the main conceptual outcome of the study – the Integrated Management Framework for Sustainable Finance and the Green Transformation of Logistics Systems, presented in Figure 2.

As shown in Figure 2, the Integrated Management Framework is built around the interaction of six main components: the institutional and regulatory environment, sustainable finance instruments, management mechanisms, ESG criteria and risk management, green and digital transformation pathways, and transformation outcomes. An important element of the framework is the monitoring, learning and feedback mechanism, through which the results of implemented transformation decisions are used to refine strategic priorities, the financing structure, and subsequent management actions.



Figure 2. Integrated Management Framework for Sustainable Finance and the Green Transformation of Logistics Systems

Source: developed by the authors based on the results of their own research (Dzwigol et al., 2021; Khaustova et al., 2022; Liashenko, Khaustova & Trushkina, 2022; Lileikiene et al., 2024; Ovchynnykova, Martinkienė & Navickas, 2024).

A key feature of the proposed framework is its departure from a linear view of financing as an initial stage followed by project implementation. Sustainable finance instruments and management mechanisms interact throughout the entire transformation cycle; ESG and risk control accompany decision-making and implementation; and the results achieved provide an information base for the next cycle of planning and investment.

Within this system, the institutional and regulatory environment is not treated as an external background, but as one of the factors shaping financial and managerial decisions. The EU Taxonomy influences the assessment of the environmental eligibility of activities; the European Green Bond Standard affects the structure and disclosure requirements for relevant debt instruments; InvestEU and CEF shape opportunities for public support and the mobilization of private capital; AFIR establishes requirements for alternative-fuels infrastructure; and CSRD influences the sustainability reporting system (European Parliament and Council, 2020; 2021a; 2021b; 2022; 2023a; 2023b).

The practical operation of this combination can be illustrated by the example of alternative-fuels infrastructure. In 2025, the European Commission selected 39 projects for support under the Alternative Fuels Infrastructure Facility, with total funding of EUR 422 million. The support covered electric recharging, hydrogen refuelling, shore-side electricity, and other solutions for road, maritime, and air transport (European Commission, 2025). This demonstrates that the implementation of capital-intensive infrastructure changes may require a combination of public resources, private capital, and risk-sharing mechanisms.

For other assets, the financing configuration may differ substantially. The modernization of warehouses, vehicle fleets, or digital systems involves more clearly defined investment objects and more predictable economic benefits, creating opportunities for green loans, leasing, or sustainability-linked financing. By contrast, cross-border and intermodal projects are characterized by a larger scale, longer implementation periods, and significant public benefits, and therefore require greater use of public co-financing and infrastructure financing mechanisms. CEF Transport has a budget of approximately EUR 25.8 billion for 2021–2027 and supports TEN-T, cross-border connections, innovation, energy efficiency, and the reduction of the environmental impact of transport (European Commission, 2021).

Figures 1 and 2 perform different but complementary functions. Figure 1 presents the logic for substantiating a financing decision for a specific transformation object. Figure 2 extends this logic to the management of the transformation process as a whole by integrating financing, the institutional environment, management mechanisms, technological pathways, ESG, risks, and outcomes into a single cyclical process.

The scientific novelty of the findings lies, first, in the proposed functional and managerial approach to sustainable finance in logistics systems. Financial instruments are systematized not only by their form, but also by their alignment with specific transformation objects, investment characteristics, technological solutions, management conditions, and risks.

Second, the Integrated Management Framework combines components that are largely examined separately in the existing literature: sustainable finance, strategic and operational management, green and digital technologies, ESG, stakeholder coordination, and risk management. In this respect, the proposed framework extends empirical findings on the interaction between green finance and logistics (Dai et al., 2025; Ozekenci & Nur, 2025) by moving from the identification of statistical relationships to the development of a management structure for transformation.

Third, the framework incorporates a monitoring, learning, and feedback mechanism through which transformation outcomes provide a basis for reviewing strategy, the financing structure, risk parameters, and subsequent investment decisions. This approach shares some features with the integrated decision-support framework proposed by Nagy et al. (2026), which combines forecasting, optimization, emissions accounting, and traceability; however, the framework developed in this study additionally integrates financial, institutional, and stakeholder dimensions.

The practical significance of the framework is evident at three levels. For logistics companies, it can be used to develop portfolios of green transformation projects and select appropriate financing structures. For financial institutions and investors, it provides a basis for aligning capital allocation with technological maturity, ESG effects, and project risk profiles. For public authorities, the framework can support the coordination of grant assistance, guarantee mechanisms, and private capital with long-term priorities for the development of transport and logistics infrastructure.

The findings provide consistent answers to the research questions posed in the study. RQ1 identifies the functional role of the main sustainable finance instruments; RQ2 systematizes the mechanisms for integrating these instruments with management, green and digital transformation, ESG, and risk management; and RQ3 develops the Integrated Management Framework, which brings these components together within a unified system for managerial decision-making, implementation, monitoring, and adjustment.

Research Limitations

The findings should be interpreted in light of several limitations. First, the Integrated Management Framework is conceptual in nature and was developed on the basis of an analysis of current scientific literature, strategic and regulatory documents, and their substantive synthesis. It has not been quantitatively validated using a sample of logistics companies or infrastructure projects. Therefore, the proposed relationships should be regarded as conceptually grounded rather than as statistically confirmed causal relationships.

The second limitation relates to the European focus

of the study. Although EU countries operate within a common regulatory environment, they differ considerably in the development of financial markets, the quality of transport infrastructure, access to capital, technological capabilities, and the pace of green and digital transformation. The practical application of the framework therefore requires the adaptation of financial and management mechanisms to national and regional conditions.

The third limitation concerns the dynamic nature of sustainable finance regulation and EU financial mechanisms. Changes in the EU Taxonomy, sustainability reporting requirements, the European Green Bond framework, CEF, InvestEU, and other instruments may affect particular parameters of the proposed framework.

Further research should focus on the empirical testing of the Integrated Management Framework with the involvement of logistics companies, financial institutions, and public authorities, as well as on comparing its application across different types of logistics assets, countries, and regions of the EU.

Conclusions

The study shows that financing the green transformation of logistics systems should be viewed not as the selection of a single "green" financial instrument, but as an integral part of a comprehensive transformation management system. The effectiveness of financing depends on how well it corresponds to the characteristics of a specific logistics asset or project, including capital intensity, payback period, cash flow structure, technological maturity, expected ESG effects, and risk level. On this basis, the principle of functional alignment is substantiated, according to which the financing structure should be designed with regard to the transformation object, its investment parameters, expected outcomes, and risk profile.

The systematization of sustainable finance instruments made it possible to identify their different functional purposes. Green bonds and other targeted debt instruments are primarily intended to mobilize long-term capital; green loans and leasing support the modernization of specific assets; sustainability-linked instruments connect financing terms with the achievement of measurable targets; public and EU funding supports infrastructure projects with high public value; guarantees and blended finance help reduce and share risks; and sustainable supply chain finance extends financial incentives for green transformation to suppliers and other participants in the value chain. Thus, there is no universal financing model for the green transformation of logistics: its configuration should depend on the type of asset, the scale and stage of the project, expected outcomes, and the level of risk.

The second result of the study is the identification of management mechanisms that enable financial resources to be converted into specific technological, organizational, and infrastructure changes. These mechanisms include strategic priority setting, project selection and assessment, financial structuring, stakeholder coordination, digital monitoring and ESG control, risk management, as well as innovation and digitalization management. This makes it possible to view capital mobilization not as a final solution, but as one of the interrelated stages of the transformation process, whose effectiveness depends on the quality of management, technological capabilities, and continuous monitoring of achieved results.

The main conceptual outcome of the study is the Integrated Management Framework for Sustainable Finance and the Green Transformation of Logistics Systems. Its scientific novelty lies in bringing together within a single management architecture the institutional and regulatory environment, sustainable finance instruments, management mechanisms, ESG criteria and risk management, green and digital transformation pathways, and transformation outcomes. Unlike approaches in which financing, green logistics, ESG, digital technologies, and risks are largely considered separately, the proposed framework reflects their interdependence throughout the entire transformation project cycle. The inclusion of a monitoring, learning and feedback mechanism ensures that economic, environmental, and operational results are used to review investment priorities, the financing structure, risk parameters, and subsequent management decisions.

The practical value of the findings lies in their potential use by different groups of stakeholders when making specific strategic decisions. Logistics companies are encouraged to develop portfolios of green transformation projects based on the type of asset, required CAPEX, payback period, projected cash flows, expected emissions reductions, and risk level. For each project, an appropriate financing configuration, a system of measurable ESG and operational KPIs, and a procedure for monitoring actual results should be defined. For large supply chains, sustainability criteria should also be extended to suppliers through sustainable supply chain finance, common ESG data requirements, and financial incentives for technological and environmental modernization.

Financial institutions and investors should assess projects not only in terms of their formal classification as green, but also with regard to technological maturity, the asset life cycle, the ability to generate cash flows, expected ESG effects, and implementation risks. For capital-intensive and innovative logistics projects, combined financing structures may be appropriate, with lending complemented by guarantees, public co-financing, or blended finance. Sustainability-linked financing, in turn, requires clearly defined KPIs, a reliable baseline, regular monitoring, and independent verification of achieved results, which can reduce greenwashing risks and improve the quality of investment selection.

Public authorities and development institutions should move from fragmented support for individual environmental measures towards the formation of portfolios of priority logistics projects aligned with the development of TEN-T, multimodality, alternative-fuels infrastructure, energy efficiency, and digitalization. A key strategic direction should be the combination of

grant funding, CEF, InvestEU, AFIF, and national mechanisms with private capital and guarantee instruments for projects that generate significant public benefits but have limited commercial attractiveness at the initial stages. At the same time, transparent project selection criteria, preliminary assessment of financial and environmental viability, and digital monitoring of the use of public funds and achieved results are essential.

Thus, the proposed approach provides a basis for moving from fragmented financing of individual environmental measures towards systematic management of the green transformation of logistics systems. Its practical significance lies in the possibility of aligning sources of capital, characteristics of logistics assets, technological solutions, institutional conditions, risks, and management mechanisms with specific economic and environmental outcomes.

A promising direction for further research is the practical implementation of the proposed Integrated Management Framework in selected logistics companies and its application to infrastructure projects in EU countries. This would make it possible to assess how the framework performs in practice and to refine its individual elements in line with the specific features of different logistics systems and national conditions.

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DIGITALIZATION AND ENERGY INDICATORS IN THE EUROPEAN UNION

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Abstract
Digitalization is increasingly recognized as a key driver of energy efficiency, renewable energy development, and the decarbonization of energy systems. Artificial intelligence, the Internet of Things, big data analytics, smart grids, and digital twins contribute to more efficient energy generation, transmission, and consumption while enhancing resource management and reducing operational costs. Nevertheless, significant differences remain among the EU Member States regarding their levels of digitalization, energy efficiency, renewable energy deployment, and greenhouse gas emissions. Assessing these differences is essential for designing effective policies that support both the digital and green transitions. The aim of this study is to develop the multidimensional measurement framework and to assess the EU Member states according to their digitalization, energy, and emissions performance. The analysis is based on the Eurostat data covering the period from 2010 to 2023. This study examines digitalization, energy and environmental sustainability in the 27 European Union Member States using the Eurostat data for 2010–2023. Principal component analysis was employed to reduce the dimensionality of the selected indicators and identify the key underlying dimensions, while hierarchical cluster analysis was applied to classify countries according to their digital, energy, and environmental characteristics. The four composite indicators were developed: energy intensity, renewable energy, digital innovation capacity, and digital business. EU Member States were classified into four groups with distinct development profiles. The Leaders cluster demonstrates the highest levels of digitalization and innovation capacity, while the Followers are characterized by strong digital business performance and highly developed economies. The Moderate group exhibits intermediate levels of technological and environmental performance, whereas the Modest group consists mainly of countries with comparatively lower digital innovation capacity and digital business development. The main contribution of this study is the development of a multidimensional framework integrating digitalization, energy, and environmental indicators to evaluate country's performance and identify policy priorities. This analysis can help identify areas requiring improvement and support policy decisions aimed at maximizing the benefits of digital transformation for energy efficiency, penetration of renewables and environmental sustainability in separate countries and the whole region. The proposed framework offers a comprehensive approach for benchmarking EU Member States, identifying strengths and weaknesses, and supporting evidence-based policymaking aimed at accelerating digital transformation, improving energy efficiency, expanding renewable energy deployment, and achieving the European Union's climate neutrality and sustainable development objectives.
KEY WORDS: Digitalization; Energy efficiency; Renewable energy; Sustainability; Principal component analysis; Cluster analysis; European Union.
JEL classification: O33 ; Q40 ; Q53

Introduction

The European Union has established the ambitious objectives of reducing greenhouse gas emissions, improving energy efficiency, increasing the share of renewable energy, and promoting the digital transformation of the economy. These goals are in line with United Nations 2030 Agenda for Sustainable Development, the Paris Agreement, the European Green Deal, and the EU climate and energy framework.

A growing body of literature suggests that digital technologies can contribute significantly to improving energy efficiency and reducing GHG emissions. Intelligent energy management systems, smart grids, predictive maintenance, and data-driven optimization facilitate more efficient energy production, transmission, and consumption while reducing energy losses and operational costs (Pakulska & Poniatowska-Jaksch, 2022; Fu et al., 2024; Jiang et al., 2024). Empirical studies have demonstrated that digitalization can reduce energy consumption and energy intensity while improving energy efficiency and supporting the decarbonization of energy systems (Xu et al., 2022; Huang et al., 2023; Song et al., 2023). Furthermore, digital technologies enhance the integration of renewable energy sources by improving forecasting accuracy, facilitating energy storage solutions, and supporting decentralized energy systems (Olabi et al., 2023; Wang & Xu, 2022; Kong et al., 2024). Digitalization also plays an important role in reducing greenhouse gas emissions. Higher levels of digitalization have been associated with increased renewable energy deployment, improved energy productivity, and lower carbon intensity of economic activities (Hao et al., 2023; Jóźwik et al., 2023; Li et al., 2025). However, the use of digital technologies requires substantial energy resources. As a result, efficiency gains may be partly offset by increased energy demand and production (Tang, 2024; Peng et al., 2024; Matthess et al., 2023). Consequently, the overall impact of digitalization on sustainability remains an important area of academic and policy debate.

This issue is particularly relevant within the European Union because Member States differ considerably in their economic structures, technological capabilities, energy systems, innovation potential, and stages of the low-carbon transition. Despite operating within a common EU policy framework, countries demonstrate different levels of energy efficiency, dependence on fossil fuels, renewable energy deployment, digital infrastructure, adoption of digital technologies by businesses, and innovation capacity. As a result, progress in one dimension does not necessarily correspond to similar progress in another. A country with advanced digital capabilities may still exhibit relatively high energy consumption or greenhouse gas emissions, whereas comparatively low emissions in another country may

partly reflect differences in economic development or industrial structure rather than superior environmental performance. This heterogeneity limits the usefulness of evaluating the EU transition solely through individual indicators. Therefore, it is essential to assess the EU member States position and progress within the European Union according to digitalization and energy system.

The multidimensional nature of digital and energy transformations requires an integrated assessment framework. Separate energy and digitalization indicators show fragmented information and make it difficult to identify broader development patterns across Member States. Thus, a multidimensional approach is needed that can provide a more comprehensive understanding of how digital and energy characteristics are related and how countries differ in their transition pathways.

Therefore, the aim of this study is to develop the multidimensional measurement framework and to assess the EU Member states position and progress according to their digitalization, energy, and emissions performance. This analysis can help identify areas requiring improvement and support policy decisions aimed at maximizing the benefits of digital transformation for energy efficiency, penetration of renewables and environmental sustainability in separate countries and the whole region.

To achieve this objective, Principal Component Analysis is applied to identify the key dimensions underlying the selected indicators, while hierarchical cluster analysis is used to classify countries according to their digital, energy, and environmental characteristics. The investigation covers 27 EU Member States and uses Eurostat data for the period 2010 – 2023. The study contributes to the literature by providing a multidimensional assessment of EU countries and by identifying their strengths and weaknesses in the context of digital and sustainable development.

The remainder of the article is structured as follows: 1) Theoretical Background section discusses the relationships between digitalization, energy efficiency, renewable energy development, and greenhouse gas emissions, providing the conceptual basis for the multidimensional assessment applied in this study; 2) Methodology section describes the selection of indicators and data, as well as the application of principal component analysis and hierarchical cluster analysis; 3) Results section presents the construction and interpretation of the composite indicators and examines the classification of EU Member States according to their digitalization, energy, and environmental performance; 4) Conclusions section summarizes the main findings and contributions of the study, discusses its limitations, and outlines directions for future research.

Theoretical Background

Digitalization has become an important factor in the transition toward more efficient and sustainable energy systems. Artificial intelligence, the Internet of Things, machine learning, big data analytics, smart grids, and Digital Twins improve the monitoring, forecasting, and management of energy systems, enhancing their safety, reliability, and operational efficiency (Pakulska & Poniatowska-Jaksch, 2022; El Zein & Gebresenbet, 2024; Kong et al., 2024). By enabling real time data collection, analysis, and automated decision making, these technologies can improve energy generation, distribution, and consumption.

Energy efficiency is also crucial for companies as they are increasingly becoming more sustainable and environmentally conscious. To achieve both cost reduction and sustainability digital technologies play a huge role. Andrei & Johnsson (2025) highlight that companies which use technologies for energy efficiency report that advanced digital technologies assist in cost reduction and achieving energy and operational efficiency as collected data gives opportunity to monitor and analyse the processes and make data-based decisions. Thus, the contribution of digitalization to energy efficiency is not limited to the automation of individual processes. Access to detailed information can improve managerial decision making by allowing firms to identify inefficient operations, compare alternative production scenarios, and allocate energy resources more effectively. For example, Internet of Things (IoT), by observing and collecting energy usage and price information in real time, might give insights regarding anomalous facts (Reichardt et al., 2025). This information assists in solving problems and searching for optimal processes. Digital twins also might contribute to large scale in reducing energy consumption for companies in different sectors. Digital twins collect all real time data and reports in real time which helps management to control workflows, which lead to lower energy consumption (Geng et al., 2026). Digital twins collect data by sensors themselves and become more autonomous and advance at each step. By having the digital twin with current date companies can test scenarios and start process optimization. Prompter decisions can be made using renewable energy, enhancing process flexibility (Mandry et al., 2025). Cloud computing, Artificial Intelligence and other digital technologies also assist in energy efficiency for companies. Guan et al. (2025) have found that companies which are using digital technologies can significantly decrease their energy intensity compared to other firms. Lower energy intensity implies that firms can potentially generate greater economic value from a given amount of energy, strengthening both their economic and environmental performance.

Through intelligent energy management, predictive maintenance, fault detection, and optimized resource allocation, digital technologies facilitate more efficient energy generation, transmission, distribution, and consumption while reducing energy losses and operational costs (Jiang et al., 2024; Fu et al., 2024; Lukianenko & Simakhova, 2024). This demonstrates that the influence of digitalization extends across the entire energy value chain. Empirical evidence supports these benefits. An analysis of 109 countries found that a 1% increase in digitalization reduces energy consumption by 0.015%, decreases energy intensity by 0.016%, and improves the energy structure by 0.008% (Xu et al., 2022). Similarly, Huang et al. (2023) reported that a 0.01

increase in the digital economy index reduced energy intensity by 0.5%, while Song et al. (2023) found that a one-percentage-point increase in the size of the digital economy increased energy efficiency by approximately 14.65 percentage points. Furthermore, a one-unit increase in digitalization within the electricity sector was associated with a reduction of 5.6041 units in the carbon intensity of electricity generation (Huang & Lin, 2023). This finding is particularly important from an environmental perspective because it indicates that digitalization may contribute not only to lower energy consumption but also to cleaner energy production.

Digital technologies also play a crucial role in supporting renewable energy deployment and integration. They improve the forecasting accuracy of wind and solar energy production, facilitate the integration of intermittent renewable energy sources with storage systems, and enhance the efficiency of decentralized energy systems such as microgrids and rooftop solar installations (Olabi et al., 2023; Wang & Xu, 2022; Kong et al., 2024). By reducing generation costs, increasing energy productivity, and optimizing energy flows, digitalization accelerates the transition from fossil fuel-based energy production to cleaner energy sources (Xie & Wang, 2023; Campana et al., 2025). It is to notice that digitalization and renewable energy development may reinforce each other. Digital capabilities facilitate renewable energy integration, while increasing renewable energy penetration creates additional demand for forecasting, monitoring, optimization, and other digital solutions.

Consequently, higher levels of digitalization are generally associated with lower energy intensity, greater renewable energy adoption, reduced greenhouse gas emissions, and more sustainable economic development (Hao et al., 2023; Jóźwik et al., 2023; Li et al., 2025). The nexus between them provides an important theoretical basis for considering digitalization, energy efficiency and GHG emissions within a common analytical framework. However, it cannot be stated as evidence that digitalization automatically improves environmental performance.

The use of digital technologies requires substantial energy and resources. Data centres, communication networks, cloud services, as well as other digital tools increase electricity demand. Also, improvements energy efficiency reduces energy cost and consequently stimulate additional production and consumption. As a result, efficiency gains may be partly offset by increased energy demand and production (Tang, 2024; Peng et al., 2024; Matthess et al., 2023). It is to notice that reductions in energy intensity do not necessarily result in proportional reductions in total energy consumption. These potentially opposing effects make the relationship between digitalization and environmental sustainability more complex.

The multidimensional nature of both digitalization and energy provides a theoretical justification for an integrated assessment of EU Member States. This assessment can help to identify whether countries demonstrating strong digital performance also achieve favourable energy and environmental outcomes. Therefore, it is extremely important to determine appropriate assessment indicators and evaluate the digitalization and energy efficiency situation across EU Member States. This provides the theoretical foundation for the multidimensional assessment framework applied in the following sections.

Methodology

Principal component analysis was used to empirically group the indicators according to the area they represent and to reduce the dimensionality of data (Mendoza-Mendoza et al., 2025). The orthogonal Varimax method was used for this purpose as it maximizes the variance of squared loadings across each component, thus facilitating a more straightforward and comprehensible factor configuration where each variable is inclined to exhibit substantial loadings on a singular factor while demonstrating minimal loadings on alternative factors. Before starting the analysis, we have examined the individual Measure of Sampling Adequacy (MSA) for each variable to indicate if a variable is suitable for the factor analysis, i.e. if its measure is greater than 0.5. Next, we have examined the overall Kaiser's Measure of Sampling Adequacy with a threshold of 0.6 to test if the entire data set is appropriate for applying factor analysis. Furthermore, we have calculated the communalities that indicate how much of the variance in each variable is explained by the common factors found in the data. We followed the rule that factors must explain at least half of the variance in individual variables (i.e., the factors obtained explain >50% of the variance in each statement). To determine the number of factors suitable for retention, an assessment of the eigenvalues derived from the correlation matrix was conducted. In accordance with the Kaiser criterion, only those factors exhibiting eigenvalues exceeding 1 were retained for subsequent analysis. Also, the proportion of the total variance of the variables explained by the factors must be at least 50%. The rotated factor loadings (in absolute values) equal or greater than 0.70 were considered very strong, 0.50 – 0.69 moderate, and 0.30 – 0.49 weak but still meaningful (Hair et al.,2019).

Cluster analysis was conducted to classify European Union countries according to their digitalization indicators, energy efficiency, renewable energy and GHG emissions. The categorization of countries into separate groups, along with the comparative assessment of their analysed indicators, can help to conduct the comparisons between the groups and within the group countries and to find out the strong and week areas of a country, which must be in the major attention of policymakers. Hierarchical cluster analysis method was employed for the investigation as the number of countries' groups was not known in advance. The execution of hierarchical cluster analysis entailed the following principal stages (Nedzinskiene & Streimikiene, 2024): 1) identification of objects for examination, 2) establishment of a variable set, 3) computation of distance metrics, 4) classification

of selected objects in accordance with the linkage rule, 5) generation of a dendrogram, 6) evaluation of the findings. Following these steps, the 27 EU counties were investigated. The initial as well as composite indicators developed in PCA analysis were used for cluster analysis. The most recent data provided by Eurostat was employed for analytical computations, while the min-max normalization technique was applied to standardize the indicators. The Euclidean distance metric and Ward's amalgamation algorithm, which aims to minimize variance within clusters, were chosen for analysis. A dendrogram was created, which delineates the degree of similarity at which any two clusters were merged and illustrates the classification of objects. The classification results were analysed and lead to the comparisons of most important indicators between the counties.

27 EU Member States were selected for the investigation. The period from 2010 to 2023 year was used as reflecting the most recent situation in EU countries. Data before 2010 were not included in the analysis because digitalization is a rapidly changing phenomenon, and older observations may not accurately reflect current patterns of digital development. The indicators for the investigation were selected according to our previous study (Nedzinskienė et al., 2025) as the created Path model in that study has revealed the most important ones in the nexus between digitalization, energy and emissions. These indicators and their main statistical characteristics for 2023 year are presented in Table1.

Table 1. The main indicators and their statistical characteristics for 2023

Indicator	Measure	Mean	Std Dev	Min	Max
GHG emissions					
GHG (Domestic net greenhouse gas emissions per capita)	Tonnes per capita	6.68	2.45	1.20	11.10
Energy efficiency					
Energy productivity (the ratio of GDP to total energy consumption).	Euro per kilogram of oil equivalent (KGOE)	9.01	4.89	2.94	26.16
Primary Energy consumption per capita	Tonnes of oil equivalent (TOE) per capita	2.82	0.96	1.57	5.61
Gross electricity production / GDP	Kilogram of oil equivalent / Eur	0.02	0.01	0.00	0.04
Final electricity consumption / GDP	kWh/Euro	0.17	0.06	0.06	0.33
Residential electricity consumption / GDP	kWh/Euro	0.05	0.02	0.01	0.13
Renewable Energy					
Share of renewable energy consumption	Percentage	27.22	13.01	14.36	66.39
Share of fossil fuels in gross available energy	Percentage	68.12	15.38	30.37	96.17
Digitalization					
Level of internet access by households	Percentage of households	93.05	3.00	86.90	99.06
Employed ICT specialists	Percentage of total employment	5.09	1.49	2.40	8.70
Total number of people receiving education	Persons per capita	0.21	0.03	0.16	0.27
Business enterprise R&D expenditure in high-tech sectors	Percentage of gross domestic product (GDP)	1.15	0.71	0.28	2.70
Enterprises with a website	Percentage of enterprises	76.06	12.60	49.85	98.27
Social media	Percentage of enterprises	63.12	14.06	38.04	87.14
Cloud / Cloud Computing Utilization	Percentage of enterprises	46.81	16.46	17.50	78.29
Enterprises with e-commerce trading activities	Percentage of enterprises	24.99	7.75	12.92	38.89
Number of patent applications	Per million inhabitants	147.17	168.44	2.21	513.19
Persons employed in science and technology	Persons per capita	0.17	0.04	0.10	0.28

Results

Principal component analysis was performed separately to Energy (energy efficiency and renewable energy) indicators as well as digitalization indicators.

Energy indicators. Before conducting the research, we have examined if a variable is suitable for the factor analysis. The individual MSA for each variable was calculated and the ones with a measure lower than 0.5. were excluded. In the case of energy indicators only the indicator Primary energy consumption with MSA value 0.413 was excluded as it did not fit well for factor analysis. Therefore, this indicator was left as individual one for further analysis. Principal component analysis was performed using the data of all the rest of the energy indicators.

The obtained the overall MSA value 0.746 exceeded the threshold of 0.6 meaning that the proportion of total variance explained by the variables was greater than 0.6, also the Bartlett's null hypothesis that the indicators are not correlated with each other was rejected ($p<0.001$). Therefore, this confirmed that the analysed data are suitable for factor analysis. We found that the communalities for all items were much greater than 0.5 meaning that the factors obtained explain >50% of the variance in each statement around its mean.

Using eigenvalues for values greater than one, we found that the indicators form 2 factors that explain 85.68% of the variance in the scale indicators. Table 2 presents the rotated component matrix. The loadings of all indicators are very strong, indicating strong correlations between the observed variables and the extracted components.

Table 2. Rotated component matrix for energy indicators

Indicators	Component	
	1	2
Final electricity consumption / GDP	.940	.269
Residential electricity consumption / GDP	.902	.267
Gross electricity production / GDP	.890	.294
Energy productivity (GDP/ total energy consumption.	-.806	.111
Share of renewable energy consumption	.072	.936
Share of fossil fuels in gross available energy	-.239	-.906

The first factor includes Final energy consumption/GDP, Residential electricity consumption/GDP, Gross electricity consumption/GDP indicators with a positive sign of loadings and Energy productivity (the ratio of GDP to total energy consumption) indicator with a negative sign of loading that have the opposite meaning than the other indicators. Higher values of energy productivity indicate more efficient energy use and lower energy intensity, while higher values of the remaining indicators reflect greater energy consumption relative to economic output. Consequently, this factor may be interpreted as representing energy intensity, where higher factor values indicate a more energy-intensive economic structure and lower overall energy efficiency, therefore, it can be called the factor of Energy intensity.

The second factor includes indicators of the Share of energy consumption (with a positive sign) and the Share of fossil fuels in gross available energy (with a negative sign). The opposite signs of these loadings reflect the inverse relationship between renewable and fossil energy sources. Specifically, higher shares of renewable energy are associated with lower dependence on fossil fuels, therefore it clearly represents the factor of Renewable energy.

Digitalization indicators. All the indicators of digitalization were suitable for factor analysis as the individual MSA for each variable was higher than 0.5. The obtained the overall MSA value 0.841 proved a high proportion of total variance explained by the variables, also the Bartlett's null hypothesis that the indicators are not correlated with each other was rejected ($p<0.001$). We have also found that the communalities for all items were greater than 0.5. Using eigenvalues for values greater than one, we found that 2 factors can be created that explain 74.44% of the variance in the scale indicators. Although the loadings of all indicators were moderate to strong, the indicator Total number of people receiving education was grouped to the factor of digital business activities. First such grouping was lacking theoretical background and second, it is a very important indicator showing the level of education in the country, so we decided to exclude it from PCA analysis and keep as individual indicator for further comparison of countries performance. The PCA analysis was run with all the rest of digitalization indicators and even better results were obtained as with very similar other measures, the newly created 2 factors explained 77.10% of the variance in the scale indicators. The loadings of all indicators were moderate to very strong (Table 3).

Table 3. Rotated component matrix for digitalization indicators

Indicators	Component	
	1	2
Level of internet access by households	.826	.197
Employed ICT specialists	.835	.348
Business enterprise R&D expenditure in high-tech sectors	.410	.593
Enterprises with a website	.624	.678
Social media	.536	.649
Cloud / Cloud Computing Utilization	.420	.736
Enterprises with e-commerce trading activities	.046	.914
Number of patent applications	.876	.340
Persons employed in science and technology	.900	.271

The first factor includes Level of internet access by households, Employed ICT specialists, Number of patent applications, Persons employed in science and technology indicators and can be called Digital innovation capacity. This component reflects the technological and innovation capacity of a country, including digital infrastructure, ICT-related human capital, scientific potential, and innovation output. High factor loadings show that countries with higher values of these indicators tend to demonstrate greater digital innovation capacity. As Business enterprise R&D expenditure in high-tech sectors, has high loadings in both factors it can also be assigned to the first one because of it shows the level of innovation more that the adoption of digital solutions in companies.

The second factor includes business related indicators: Enterprises with a website, Use of social media, Cloud / Cloud Computing Utilization, Enterprises with e-commerce trading activities, thus, it can be named Digital business factor. This component represents the practical adoption and integration of digital technologies in business activities. It captures the extent to which enterprises use digital tools, online platforms, cloud technologies, and e-commerce solutions in their operations.

Final list of indicators. It is to summarize that PCA analysis revealed 2 composite energy and 2 digitalization indicators. These composite indicators together with the initial ones that are also very important for the analysis will be used for further investigation. The indicators and their interpretations are provided in Table 4.

Table 4. The final list of indicators

	INDICATOR	**SINGLE / COMPOSITE**	**INTERPRETATION**
EMISSIONS	GHG emissions per capita	Single	The lower - the better, but depends on economic development of a country
ENERGY	Primary Energy consumption per capita	Single	The lower - the better, but depends on economic development of a country
	Energy intensity	Composite	The lower - the better
	Renewable energy	Composite	The higher – the better
DIGITALIZATION	Total number of people receiving education	Single	The higher – the better
	Digital innovation capacity	Composite	The higher – the better, but the rebound effect should be considered
	Digital business	Composite	The higher – the better, but the rebound effect should be considered

Environmental and energy indicators are generally interpreted according to the principle that lower greenhouse gas emissions, lower primary energy consumption, and lower energy intensity reflect better sustainability performance and more efficient resource use. However, greenhouse gas emissions and primary energy consumption per capita should be interpreted with caution, as lower values may also be associated with lower levels of economic development and industrial activity. In contrast, higher shares of renewable energy indicate a cleaner and more sustainable energy structure, contributing positively to the low-carbon transition.

Regarding digitalization, higher levels of education, digital innovation capacity, and digital business development are generally considered favourable, as they reflect stronger technological advancement, innovation potential, and digital transformation. Nevertheless, the potential rebound effect should also be considered, since

digitalization may simultaneously increase energy consumption and resource use despite efficiency improvements.

The final list of indicators was used for the classification of 27 European Union countries according to their performance in digitalization, energy and emissions areas. The data were normalized using min-max method, the Euclidean distance metric and Ward's amalgamation algorithm were applied and a dendrogram was created (Figure 1):

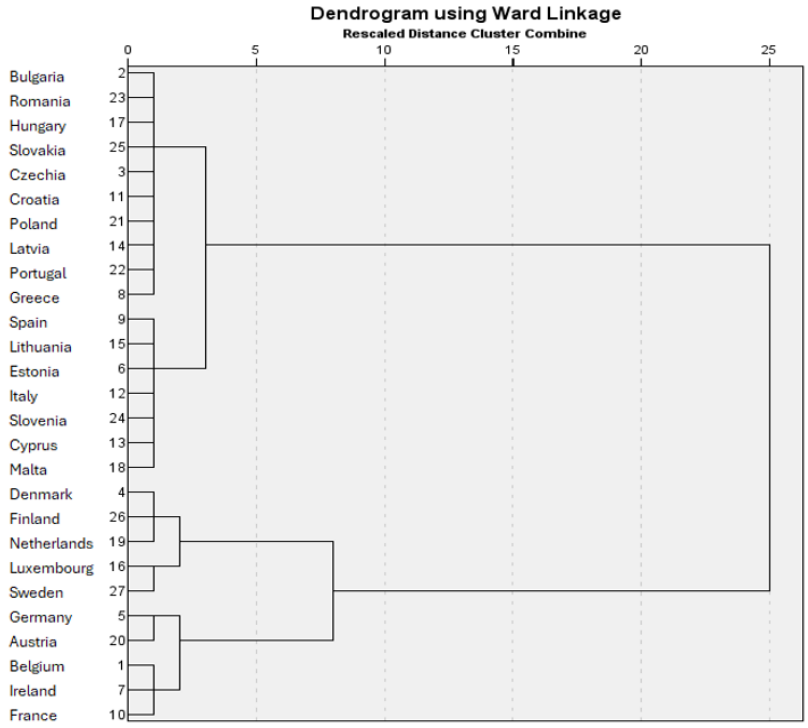


Fig. 1. The dendrogram

It was found that EU countries can be clearly classified into the 4 main groups according to their indicators. The summarized data of each group and its indicators are presented in Table 5.

Table 5. Average normalized indicator values for each group of countries

	Indicators						
Group of countries	GHG emissions per capita	Primary Energy consumption per capita	Energy intensity factor	Renewable energy factor	Total number of people receiving education	Digital innovation capacity	Digital business
Leaders: Denmark, Luxembourg, Netherlands, Finland, Sweden	0.61	0.63	0.32	0.57	0.73	0.66	0.72
Followers: Belgium, Germany, Ireland, France, Austria	0.72	0.37	0.27	0.34	0.65	0.37	0.72
Moderate countries: Estonia, Spain, Italy, Cyprus, Lithuania, Malta, Slovenia	0.48	0.21	0.42	0.28	0.34	0.24	0.67
Modest countries: Bulgaria, Czechia, Greece, Croatia, Latvia, Hungary, Poland, Portugal, Romania, Slovakia	0.49	0.19	0.56	0.31	0.35	0.18	0.43

Leaders (Denmark, Luxembourg, Netherlands, Finland, and Sweden) demonstrate particularly high values of digital innovation capacity, digital business development, and education indicators. Sweden and Finland also exhibit the strongest renewable energy performance among all groups. However, several countries in this cluster, especially Luxembourg and Finland, show relatively high greenhouse gas emissions and primary energy consumption per capita, reflecting the higher levels of economic activity and consumption characteristic of highly developed economies. Nevertheless, this group generally demonstrates strong

progress toward a low-carbon economy supported by advanced technological and digital capabilities.

Compared to the Leaders, the level of digital innovation capacity is more moderate in the Followers group (Belgium, Germany, Ireland, France, and Austria). France and Austria demonstrate comparatively stronger renewable energy performance and lower greenhouse gas emissions, while Ireland and Germany exhibit higher greenhouse gas emissions per capita. Overall, this cluster reflects economically advanced countries where digitalization is well developed, although progress toward environmental sustainability differs among the countries.

Moderate countries (Estonia, Spain, Italy, Cyprus, Lithuania, Malta, and Slovenia) have relatively low primary energy consumption per capita and moderate greenhouse gas emissions, but it can be related to the lower economic development compared with the Leaders and Followers. Several countries, particularly Lithuania and Malta, show strong digital business development despite comparatively weaker digital innovation capacity. Renewable energy performance within the group remains moderate, indicating an ongoing but uneven transition toward a low-carbon economy.

Modest countries (Bulgaria, Czechia, Greece, Croatia, Latvia, Hungary, Poland, Portugal, Romania, and Slovakia) demonstrate the highest energy intensity values, especially in Bulgaria, indicating lower levels of energy efficiency and greater dependence on energy-intensive economic structures. Although greenhouse gas emissions and primary energy consumption per capita are relatively low in several countries, particularly Romania and Portugal, these results may partly reflect lower levels of economic development and industrial activity rather than higher sustainability performance. Renewable energy development remains moderate or relatively weak in most countries of this cluster, meaning structural changes are still required in these countries.

Conclusions

The results of this study have revealed substantial differences among EU Member States in terms of digitalization, energy intensity, renewable energy and GHG emissions. Principal component analysis has identified four composite indicators: Energy Intensity, Renewable Energy, Digital Innovation Capacity, and Digital Business that can be used as a framework to assess the countries' performance in terms of digitalization and sustainability.

Cluster analysis distinguished four groups of countries with different development patterns. The Leaders group represents the most advanced cluster in terms of digitalization and innovation. The Followers group is characterized by highly developed economies with strong digital business performance and relatively high educational attainment. The Moderate countries' group have moderate environmental and technological performance, while the modest countries are mainly the countries with lower levels of digital innovation capacity and digital business development.

Limitations and Future Research. The main limitation of this study is that it identifies patterns and similarities among countries but does not establish causal relationships. Future research could apply econometric methods to examine causal relationships. Further studies could also investigate the potential rebound effects of digitalization on energy efficiency and environmental performance.

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AI-MEDIATED PLATFORM WORK: MEANINGFULNESS UNDER ALGORITHMIC MANAGEMENT

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Abstract
Artificial intelligence increasingly mediates how platform work is matched, monitored, evaluated and performed. This conceptual paper develops a meaningfulness-based framework for AI-mediated platform work. Gig and platform work provide the bounded empirical setting because automated coordination, opaque evaluation, fluctuating demand, dependence on ratings and limited possibilities for contestation make the relevant tensions especially visible. The scientific problem is the under-specification of how co-occurring substitution and augmentation within a task bundle interact with platform-level control and governance to shape the significance workers attribute to a focal work episode. The purpose is to specify that relationship. The object is the AI-mediated platform-work episode, operationalized through its task bundle; the subject is the relationship among task-level AI effects, platform-level control and governance, meaningfulness pathways and worker context. Drawing on theory synthesis and abductive model development, the article integrates research on gig work, algorithmic management, task-based labour economics and meaningful work. Contextual evidence from the OECD, the European Union and the World Bank establishes the scale and relevance of the setting but does not test the proposed relationships. Substitution and augmentation are treated as non-exclusive task-level effects, and control intensification as a cross-cutting platform-level effect. Algorithmic management is treated as the governance layer surrounding task execution rather than as a synonym for AI use within tasks. Following Rosso, Dekas and Wrzesniewski (2010), the model locates experienced meaningfulness at worker level and distinguishes four pathways: individuation, self-connection, contribution and unification. Five continuous task-bundle descriptors characterize configurations in which AI may replace or support human activity. Five platform-governance arrangements are proposed to preserve or expand opportunities to enact the pathways: rule intelligibility, credible human contestability, worker voice, capability development and relational infrastructure. Worker values and cultural or interpersonal cues are proposed to shape pathway salience, while livelihood dependence and material or institutional security condition practical access to the governance arrangements. Seven propositions specify these relationships and are formulated for testing with episode-level measures nested within workers and platforms. Because experienced meaningfulness is associated with engagement, performance and retention (Bailey et al. 2019), the model also indicates where platform design decisions may carry organizational consequences. The contribution is a level-specific model for examining meaningfulness in AI-mediated platform-work episodes. Transferability beyond gig and platform work remains a question for future research.
KEY WORDS: AI-mediated platform work, algorithmic management, meaningful work, gig work, platform governance, task bundles
JEL Classification: J81, M54, O33

Introduction

Gig and platform work make AI-mediated coordination especially visible. The World Bank estimates that online gig work alone may involve between 154 million and 435 million workers globally and that platform workers and clients are located in 186 countries (Datta et al. 2023). In the European Union, policy attention has intensified around the more than 28 million people working through digital labour platforms, a figure reported in Council communications on the Platform Work Directive (Council of the European Union 2024). Its scale makes platform work relevant to management research: it is a revealing setting in which to examine how work is reorganized under digital coordination. In this paper, however, platform work is a bounded empirical context rather than a proxy for all AI-mediated work.

At the same time, platform work is becoming more deeply intertwined with AI and algorithmic management. OECD data show that, in OECD countries where data are available, the share of firms using AI rose from 8.7% in 2023 to 14.2% in 2024 and 20.2% in 2025, meaning that firm-level adoption more than doubled in only two years (OECD 2026). In Europe, the JRC AIM-WORK survey of 70,316 people aged 16–65 across all 27 Member States indicates that 30% of EU workers use AI tools at work, 37% have their working hours digitally monitored, 24% have working time allocated automatically, and 13% have their performance assessed and rewarded automatically (González Vázquez et al. 2025). These figures establish the wider relevance of AI use, digital monitoring and automated coordination; they do not determine whether the relationships proposed here for platform work hold in standard employment.

The dominant promise of the platform-work model is flexibility: workers can choose when and where to work, while firms can scale labour in response to volatile demand. Yet flexibility is frequently bundled with wage volatility, weak social protection, opaque evaluation criteria and asymmetrical dependence on platform rules (De Stefano 2016; Wood et al. 2019). Generative AI adds another source of heterogeneity. In a customer-support setting, Brynjolfsson, Li and Raymond (2025) found that productivity gains were largest among novice and lower-skilled workers. In an online labour market, Hui, Reshef and Zhou (2024) found short-term reductions in employment and earnings among freelancers in occupations more exposed to generative AI. Because the studies examine different technologies, tasks, settings and workers,

they do not establish that productivity gains for a task caused earnings losses among the people who previously performed it. Read together, they support a heterogeneous rather than uniform account of AI's relationship with work.

The article therefore examines task execution and algorithmic governance together within gig and platform work. Its central question is how AI's effects on the components of a platform-work episode and algorithmic management's effects on the platform governing that episode jointly relate to the significance the worker attributes to it. The unit of analysis is the work episode: a single assignment, service encounter or project, together with the task bundle through which it is completed. It is not the worker or the occupational category. Substitution and augmentation may occur separately or together within one bundle; control intensification is a cross-cutting platform-governance effect rather than a third task effect. The paper contributes a level-specific framework connecting task reconfiguration, platform governance and worker-experienced meaningfulness in gig and platform settings.

The scientific problem is the under-specification of how substitution and augmentation within AI-mediated platform-work episodes relate to platform-level algorithmic governance and to the significance workers attribute to those episodes. The purpose of the article is to develop a meaningfulness-based conceptual model of this relationship. The research object is the AI-mediated work episode in gig and platform settings, operationalized through its task bundle; the research subject is the relationship among task-level AI effects, platform-level control and governance arrangements, Rosso et al.'s (2010) pathways, and worker values, cultural cues, livelihood dependence and material or institutional security. The article uses theory synthesis and conceptual model development, supported by contextual descriptive evidence. Its benefit for science is a set of propositions for future empirical testing; its benefit for business and platform design is a diagnostic framework for responsible algorithmic governance; and its benefit for education and professional training is a coherent teaching model that separates task configuration, platform governance and worker experience.

Three research questions structure the argument. RQ1 asks how substitution and augmentation, separately or together within the task bundle of a focal work episode, alter opportunities to enact the four pathways. RQ2 asks how platform-level control and platform-governance arrangements constrain or expand those opportunities. RQ3 asks how worker values, cultural or interpersonal cues, livelihood dependence and security shape pathway salience and practical access to the governance arrangements.

Literature analysis and gap identification

Gig work as a paradox of autonomy and precarity

Research on gig work repeatedly shows that platform labour cannot be reduced either to entrepreneurial freedom or to pure exploitation. It is characterized by a constitutive tension between localized autonomy and structural dependence. Workers may value temporal flexibility and market access, yet algorithmic control and labour oversupply restrict the autonomy available in practice (Wood et al. 2019), and platform work sits within a wider expansion of precarious employment systems (Kalleberg 2011). The literature is particularly strong at diagnosing asymmetry, but it is less developed as an organizational design literature. It explains why workers are vulnerable more readily than it explains how platform-like systems might be redesigned.

AI and algorithmic management as a new organizational regime

The second stream concerns algorithmic management. The International Labour Organization (n.d.) describes algorithmic management as the use of algorithmic systems, informed by tracked data and other information, to organize, assign, monitor, supervise and evaluate work. Such systems may use AI but may also be rules-based; algorithmic management is therefore treated here as the governance layer around, rather than as a synonym for, AI use within tasks. Kellogg, Valentine and Christin (2020) synthesize this field through the six Rs of algorithmic control: restricting, recommending, recording, rating, replacing and rewarding. Their account is analytically useful because it shows that algorithms do not simply automate tasks; they redistribute authority, information and dependence. Vadyba research on AI-based freight coordination similarly treats AI as a coordination technology that automates information management and supports route planning in dynamic supply-chain settings (Gružauskas and Pačėsaitė 2021). Reviewing the same field through a work-design lens, Parent-Rocheleau and Parker (2022) identify six management functions that algorithms now perform: monitoring, goal setting, performance management, scheduling, compensation and termination. They conclude that, on balance, these functions tend to intensify work and reduce autonomy.

At the same time, algorithmic management does not have uniform relationships with worker outcomes. Recent studies report heterogeneous associations in gig work (Liu and Yin 2024; Kadolkar, Kepes and Subramony 2025). The relevant question is therefore under which organizational conditions workers experience AI-mediated coordination as enabling, arbitrary, developmental or extractive.

Meaningful work and the heterogeneity of gig work

Meaningful work scholarship adds a critical normative and analytical lens (Bailey et al. 2019). Rosso, Dekas and Wrzesniewski (2010) separate two ideas. The meaning of work is what work signifies to a person; meaningfulness is the amount of significance that work holds for that person. Meaningful work, in this paper, is work the worker experiences as especially significant and positive in meaning. The definition locates meaningfulness at worker level: a platform may enable or obstruct the experience but cannot produce it uniformly. Workers also participate in making meaning, which remains relevant

under gig conditions: Affolter, Spurk and Straub (2025) find that active meaning-making weakens the association between gig-work challenges and work alienation. In digitally mediated settings, task, relational and interpretive conditions may shift together. Workers may receive efficiency signals without narrative recognition, market access without developmental pathways, and performance feedback without explanation. The resulting tensions are economic, interpretive and relational.

Prior taxonomies of gig and platform work already make this disaggregation possible. Howcroft and Bergvall-Kåreborn (2019) cross-classify crowdwork platforms by the party that initiates the work and by the form of remuneration, while Schmidt (2017) distinguishes platforms by whether tasks are location-bound and whether they are assigned to a selected individual or to an undefined crowd; both accounts note that the boundaries between their types are blurred and that hybrid forms exist. Berg et al. (2018) add the decent-work perspective, showing how online labour platforms vary in pay setting, task allocation, communication and dispute resolution. Vallas and Schor (2020) likewise argue that platforms do different things across sectors rather than expressing a single organizational logic. These taxonomies are used here for what they show - that platform work varies along several dimensions at once and that the lines between its forms are porous - and not to sort workers or occupations into exclusive categories of AI effect.

This problem becomes sharper once gig work is disaggregated. Online codifiable work such as microtasks or routine writing, location-based embodied services such as delivery or ride hailing, and expert project-based freelance work remain useful illustrations, but none is tied to a single AI effect. Within one work episode AI may perform some components, assist the worker with others, and coexist with platform systems that tighten monitoring or evaluation: a delivery keeps its embodied execution while route planning is automated; a design commission combines automated generation with contextual interpretation, client negotiation and human responsibility for the result; a microtask batch combines automated preprocessing with human verification. What varies is not the category a worker belongs to but the components themselves - how codifiable and remotely verifiable they are, how much contextual judgement they require, how far they depend on embodied or relational interaction, and how much discretion the worker held before AI entered. These characteristics vary continuously across task bundles, and one bundle can score high on several of them at once.

Four pathways to meaningfulness

Rosso, Dekas and Wrzesniewski's (2010) integrative framework locates four pathways at the intersections of two dimensions: agency versus communion and orientation toward the self versus others. Individuation concerns self-directed agency expressed through efficacy, competence and achievement. Self-connection concerns alignment between work and how the worker understands and values the self, including authenticity and identity affirmation.

Contribution concerns other-directed agency expressed through attributable impact or service beyond the self. Unification concerns belonging and connection with other people, collectives or valued principles. The pathways are non-exclusive, and several may be relevant within the same episode. The framework identifies possible routes to meaningfulness; the worker remains the level at which the significance of the episode is experienced.

The salience of a pathway is not assumed to be culturally uniform. Rosso, Dekas and Wrzesniewski (2010) review cultural and interpersonal sensemaking as mechanisms through which work meanings are constructed, but they do not test culture as a moderator of the four-pathway model. Martela and Riekki (2018) provide adjacent rather than direct evidence: in samples from Finland, India and the United States, autonomy, competence, relatedness and beneficence were independently associated with meaningful work, with the exception of competence in the United States. These constructs are related to, but not equivalent to, Rosso et al.'s four pathways, and the study does not test cultural moderation of those pathways. The proposition developed below (P6) is therefore a theoretical extension: worker values and salient cultural or interpersonal cues are proposed to shape which pathways carry significance and how strongly. Culture is not a fifth pathway, and country membership is not used as its proxy; empirical tests would need to measure values, norms and relevant social cues directly.

Synthesis of the research gap

Taken together, these literatures reveal a fragmented field. Gig-work research diagnoses insecurity and asymmetry; algorithmic-management research explains new forms of control; meaningful-work research specifies what good work requires; and task-based labour economics explains why automation acts on bundles of tasks rather than on whole occupations (Autor 2015; Acemoglu and Restrepo 2022). Recent Vadyba bibliometric work on AI-based innovation management points to a related gap: technical, managerial and societal dimensions of AI remain insufficiently integrated in ways that limit both theoretical advancement and practical guidance (Gajda, Górska-Warsewicz and Podleśna 2025). Adjacent studies cover parts of this relationship: Bankins and Formosa (2023) relate replacement, machine-tending and amplification to meaningful work and allow them to coexist; van Zoonen, ter Hoeven and Morgan (2023) and van Zoonen, Sivunen and Treem (2024) link algorithmic coordination, quantification and control to crowdworkers' work conditions, identity, belonging and meaningfulness; Liu et al. (2026) review how digital technologies alter work characteristics and meaning-making under societal, organizational, technological and individual conditions; and García-Ruiz and Rocchi (2026) set out normative conditions for meaningful work under algorithmic management. Against this background, one relationship remains underspecified: how co-occurring task-level substitution and augmentation interact with platform-level governance to alter particular pathways within a focal work episode. The contribution is therefore a governance-specific and

level-consistent extension of adjacent frameworks, not a claim that prior integrative models are absent.

Contextual descriptive evidence and research method

The descriptive indicators cited in the Introduction measure different phenomena in different populations: the scale of online gig work (Datta et al. 2023), firm-level AI adoption in OECD countries where data are available (OECD 2026), and AI use, digital monitoring and automated coordination among EU workers (González Vázquez et al. 2025). Their role is contextual. Together they establish the scale and relevance of platform labour and digitally mediated coordination, but they are not directly comparable. They neither estimate the prevalence of the proposed mechanisms in platform work nor provide evidence for the propositions.

The paper combines the Theory Synthesis and Model approaches described by Jaakkola (2020). This combination is appropriate because the article connects constructs from several literatures and specifies their relationships at task, platform and worker levels in a single conceptual model. Model development follows an abductive logic in the limited sense described by Tavory and Timmermans (2014): it iterates between tensions documented in the cited literature and concepts capable of explaining them. Continuous task characteristics are used as descriptors for comparing task-bundle configurations rather than as a labour-market taxonomy. The resulting propositions are theoretical predictions; they are not presented as effects established by the contextual indicators or by a systematic review conducted for this article.

A meaningfulness-based framework for AI-mediated platform work

The framework proposed here (see Fig. 1) treats gig work as a differentiated domain rather than a uniform organizational form. Its focal unit is the AI-mediated work episode, operationalized as the task bundle through which one platform assignment, service encounter or project is completed. An episode enters the model when AI performs or supports at least one task component, when an AI-based platform system mediates its allocation, direction, monitoring or evaluation, or both. Purely rules-based systems remain elements of the surrounding governance architecture but do not by themselves make an episode AI-mediated. Within the bundle, substitution occurs when AI assumes a component that would otherwise require human labour; augmentation occurs when AI supports or extends performance while the worker retains a substantive role in judgement, action or responsibility. The two effects are non-exclusive. This logic draws on task-based labour economics, which treats automation as affecting bundles of tasks rather than occupations as whole categories (Autor 2015; Acemoglu and Restrepo 2022). Codifiability, remote verifiability, required contextual judgement, embodied or relational interdependence and prior worker discretion are used to describe and compare configurations in which substitution and augmentation may occur. They do not determine either effect mechanically.

Consistent with algorithmic-management research, the framework treats coordination technologies as possible instruments of control rather than as neutral efficiency devices (Kellogg, Valentine and Christin 2020; Parent-Rocheleau and Parker 2022). Algorithmic matching, monitoring and evaluation can intensify supervision while presenting it as technical optimization. Control intensification is defined here as an increase in the scope, granularity, speed or consequences of platform allocation, direction, monitoring, evaluation, reward or sanction. It is a platform-level governance effect rather than a third task-level alternative: the same episode may combine task augmentation with tighter platform control. Because workers encounter formal governance through particular episodes, their exposure may vary even within one platform. The model examines how that exposure alters opportunities to enact the four pathways.

The framework distinguishes five platform-governance arrangements with pathway-specific functions. Rule intelligibility makes consequential rules and the reasons for outcomes comprehensible. Credible human contestability provides timely appeal, correction and exception handling by a reviewer able to change the outcome. Worker voice concerns prospective influence over consequential rules rather than appeal after a decision. Capability development includes feedback, learning, portable credentials and job-crafting opportunities; job crafting involves workers' active reshaping of cognitive, task and relational boundaries (Wrzesniewski and Dutton 2001), and it supports agency only when workers retain discretion to apply what they learn. Relational infrastructure sustains peer belonging and recognition and may also make beneficiaries and the worker's attributable impact visible; the former supports unification, whereas the latter supports contribution. These arrangements do not guarantee a positive experience. They are proposed to preserve or expand opportunities to enact particular pathways.

Two conditions outside the focal task bundle perform different functions in the model. Worker values and salient cultural or interpersonal cues are proposed to shape the interpretation and relative salience of the pathways. Livelihood dependence and material or institutional security are proposed to condition workers' practical access to governance arrangements: refusal, appeal, participation, development and connection may exist formally but remain costly to use. The model's endpoint is the worker's experienced meaningfulness of the focal episode. An episode may acquire significance partly because it develops capabilities that can credibly be used later, but the accumulation of experiences across episodes into an enduring evaluation of one's work or career lies outside the present model.

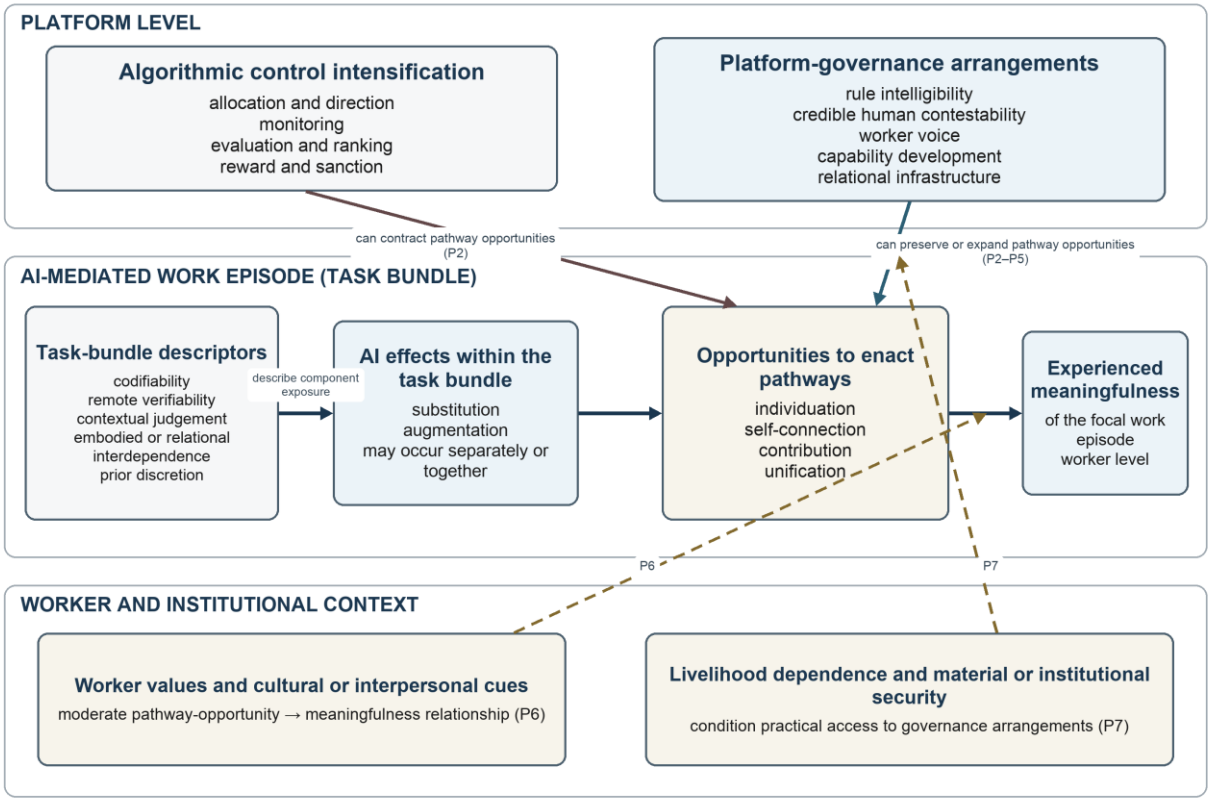


Fig. 1. Task, governance and contextual conditions of meaningfulness in AI-mediated platform work

Propositions

The framework yields seven propositions specifying relationships for future empirical testing. P1 connects task reconfiguration to changes in pathway opportunities; P2–P5 connect platform governance to those opportunities; P6 addresses pathway salience; and P7 addresses practical access to governance arrangements.

P1. Changes in opportunities to enact the four pathways mediate the relationship between AI-related task reconfiguration and experienced meaningfulness. Relative to a prior or functionally comparable task configuration, reconfiguration is positively associated with the meaningfulness of a focal episode when it expands opportunities for efficacy and competence enactment (individuation), identity-aligned action (self-connection), attributable impact (contribution), or human and collective connection (unification), and negatively associated when it contracts those opportunities. Because substitution and augmentation may occur separately or together, neither has a uniformly positive or negative association independent of the resulting pathway changes. When changes across pathways diverge, their relationship with experienced meaningfulness depends on pathway salience as specified in P6.

P2. Greater episode-specific exposure to platform-level control intensification is negatively associated with experienced meaningfulness to the extent that it contracts opportunities to enact one or more pathways. This negative association is weaker when the rules and reasons underlying consequential decisions are intelligible and workers have access to credible, timely human contestability. These arrangements most directly preserve agency and efficacy but do not imply that control can affect only individuation.

P3. Worker participation in setting or revising consequential platform rules is positively associated with opportunities for individuation and, when participation is collective, unification, provided that worker input can alter the rules or their implementation. Mechanisms that merely collect views without the capacity to influence decisions are not expected to have the same relationship.

P4. Capability-development and job-crafting opportunities are positively associated with individuation and self-connection when workers retain discretion to apply and demonstrate what they learn within the focal task bundle or perceive the acquired capability as credibly portable to subsequent work.

P5. Relational infrastructure that enables credible peer interaction, support and recognition is positively associated with opportunities for unification, whereas credible visibility of beneficiaries and of the worker's attributable impact is positively associated with opportunities for contribution.

P6. The positive association between an opportunity to enact a pathway and the experienced meaningfulness of a focal episode is stronger when that pathway is congruent with the worker's values and salient cultural or interpersonal cues. The proposition concerns directly measured values, norms and social cues rather than deterministic differences between countries.

P7. High livelihood dependence combined with weak material or institutional security weakens the extent to which formally available governance arrangements translate into usable opportunities for voice, contestability, development and connection, because refusal, exit or

appeal carries a higher practical cost. Stronger material or institutional security attenuates this constraint. This condition concerns practical access to governance arrangements rather than pathway salience.

Discussion and implications

The framework makes three theoretical contributions. First, it separates two levels that are often conflated in accounts of platform work: AI substitutes for or augments components within a task bundle, whereas algorithmic management governs allocation, direction, monitoring, evaluation, reward and sanction at platform level. This distinction prevents control intensification from being treated as a third task effect.

Second, the framework represents heterogeneity through continuous task-component descriptors rather than mutually exclusive worker or occupational categories. A single episode may therefore contain substituted and augmented components while remaining subject to intensified platform control. Third, the framework uses Rosso et al.'s four pathways to distinguish between the opportunities made available by task and governance configurations, the pathways a worker considers salient, and the worker's practical ability to use formally available arrangements. Values and cultural or interpersonal cues address salience; livelihood dependence and security address practical access.

For managers and platform designers, the framework implies that efficiency metrics alone are inadequate. Experienced meaningfulness has been associated with engagement, performance and retention (Bailey et al. 2019), so governance choices that contract pathway opportunities are not only a normative concern. Governance arrangements should be matched to task-bundle characteristics and evaluated in terms of whether workers can understand, influence and contest consequential decisions and retain opportunities for learning and connection. A configuration suitable for routine, benchmarkable components should not automatically be transferred to episodes dominated by embodied service, contextual judgement or client interaction, where discretion and relational recognition may be more consequential.

For policy, the argument aligns with current efforts to improve transparency and worker protection in platform work. The EU Platform Work Directive adopted in 2024 seeks to clarify employment status, increase transparency in automated monitoring and decision-making systems, secure human oversight and review of significant decisions, and restrict some forms of personal-data processing by digital labour platforms (Directive (EU) 2024/2831). In the present model, such safeguards can strengthen credible contestability and institutional security. Whether they alter workers' experience in practice remains an empirical question.

Several limitations should be acknowledged. The paper is conceptual rather than empirical, the descriptive evidence is illustrative rather than harmonized, and the studies synthesized here do not test the complete seven-proposition model. The propositions are therefore predictions rather than established effects. The task-bundle abstraction simplifies a labour market in which episodes may combine digital, embodied, relational and expert components and in which workers and platforms may define episode boundaries differently. The model treats the focal episode as the unit of observation; cumulative changes across episodes and longer-term evaluations of work or career lie outside its present scope. Finally, the framework is bounded to gig and platform work. Standard employment, professional regulation, collective bargaining and career structures may change the proposed relationships, so transferability should be established rather than assumed.

Conclusions

The article offers an explanation of how AI-related task reconfiguration and platform governance may shape the significance workers attribute to a focal platform-work episode. Its central implication is that this experience should be examined through changes in pathway opportunities and workers' practical access to governance arrangements, rather than inferred from an occupational category or from the presence of AI alone.

Future empirical work should test the seven propositions with measures aligned to the model's levels: task-component exposure within episodes; platform governance and control; worker-reported opportunities to enact the four pathways; and experienced meaningfulness of the focal episode. Repeated observations of several episodes nested within workers and platforms would help separate episode variation from stable worker values and platform rules. Comparative studies should measure cultural values, interpersonal cues, livelihood dependence and access to protection directly rather than use country or occupation as proxies. Occupational AI-exposure indicators may help identify settings (Felten, Raj and Seamans 2021; Eloundou et al. 2024), but they cannot substitute for component-level measures when the unit of analysis is the work episode.

For business and platform design, the relevant question is not only whether governance arrangements formally exist but whether workers can use them without unacceptable risk. Explanation, appeal, participation, learning and peer-support mechanisms offer limited protection when dependence on the platform makes their use practically costly.

For education and professional training, AI-mediated platform work should be taught as a socio-technical management problem rather than only as a technical automation issue. Managers, platform designers and students should be trained to evaluate platform AI systems through efficiency, legality, fairness, worker development and worker-experience criteria.

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AI-assisted language editing, document-formatting support and source-consistency checking were used during final manuscript preparation. No AI system is listed as an author. The author accepts full responsibility for the originality, accuracy and integrity of the submitted work.

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THE NECESSITY OF INVESTMENT DRIVEN BY OPERATIONAL CHANGES: THE CASE OF THE MUNICIPAL SECTOR

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Abstract
The green transformation promoted by the European Union (EU) affects not only infrastructure, but also managerial work organization decisions. By 2050, the EU has set a goal to decarbonize the environment and use only clean technologies for energy production. Changing legal regulations encourage investment development, which affects the work of both business entities and other organizations. The need for management skills and the change of competencies is becoming one of the most serious challenges in implementing important infrastructure projects. When it comes to the municipal energy production sector, not only the need to evaluate investment decisions, but also aspects of ensuring security of supply are highlighted. The article presents an example of the transformation of the municipal heating sector at the municipal level in Lithuania, while emphasizing the need for management changes. The possibilities of replacing worn-out heat production infrastructure are assessed, considering the goals set by the EU. Both traditional investment payback methods and innovative approaches, such as Response Surface Methodology, were employed for this purpose. The research conducted in the article showed that investments in new-generation infrastructure are inseparable from a comprehensive assessment, taking into account the future prospects of the region. The results of the article showed that it makes the most sense to undertake investments that are related to the application of new and innovative technologies, while ensuring operational flexibility. Nevertheless, it is important to consider the specific context of the location, as the most efficient solution may prove economically unviable due to site-specific characteristics and long-term prospects. The necessity of investments highlights the importance of managerial decisions – decisions on attracting investments, searching for optimization opportunities and maintaining operational competitiveness. When assessing investments, it is very important to consider the regional context and development prospects, thus finding the most favorable production technology in the long term.
KEY WORDS: energy transformation, management solutions, municipality, rural development.
JEL Classification: O18, Q20, P25

Introduction

The need to assess the performance of new generation equipment and the resulting change in management decisions arises from the European Union's position on environmental protection. The EU has long based its activities on green technologies, environmental protection and the recently added component of energy independence. The European Union's policy in the 2021-2027 perspective has become clearly based on the European Green Deal. The course included specific and targeted transformation directions in the cases of decarbonization of energy production, agriculture, and transport. At the same time, this must create conditions for energy independence by reducing the import of energy resources from Third World countries. In quantitative terms, the goal of reducing greenhouse gas emissions by 80–95% by 2050 was set (European Commission, 2025). Preparatory work for the adoption of directives took place until 2020, which regulated the following aspects:

- Directive 2009/28/EC of the European Parliament and of the Council on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC6 Directive 2009/29/EC of the European Parliament and of the Council amending Directive 2003/87/EC so as to improve and extend the Community greenhouse gas emission allowance trading scheme (EUR-Lex, 2009);
- Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions (integrated pollution prevention and control) (EUR-Lex, 2010).

In particular, heat production is considered part of the overall decarbonization plan in this case. This is related to the uneven demand for heat production in the EU. In the case of decarbonization of heat production, the main focus is on separate communications dedicated to this sector:

- European Commission Communication “Energy 2020. A strategy for competitive, sustainable and secure energy”. Target indicator – achieving the 2/3 clean heat production target, increasing the share of centralization and cogeneration (combined heat and power production) (EUR-Lex, 2020).
- European Commission Communication “Stimulating a climate-neutral economy: A strategy for the integration of the EU energy system”. The main emphasis is on increasing the influence of heat pumps, while expanding the production of green electricity in decentralized heat production sources (European Committee of the Regions, 2021).

The EU's position on the green transformation is supported by the allocation of structural funds, the promotion of innovation, as well as the development of electricity networks. The green transformation was primarily supported by the installation of wind farms

(Barthelmie & Pryor, 2021). Later, with the solar energy breakthrough, more and more areas in the Baltic States, Poland, Italy, Germany, and Romania were allocated for the installation of solar panels (Lebedeva et al, 2025; Igliński et al, 2023; Raihan et al, 2024; Gómez-Calvet & Gomez-Calvet, 2025; Prăvălie et al, 2022). These technologies are made even more efficient by Battery Energy Storage System (BESS) systems, which create conditions for storing energy (Mohamad et al, 2021; Tejero-Gómez, & Bayod-Rújula, 2023). Biomass utilization remains important in terms of biowaste utilization (SOURCE), and new generation biomethane production technologies allow for the decarbonization of the transport sector (Noussan et al, 2024). These changes significantly affect the management systems of companies managing this infrastructure – there is a need to have strong technology and remote management departments, as well as strong energy sales specialists working with virtual electricity exchanges (Li, 2024; Zhou et al, 2025).

In addition to the development of new infrastructure, the search for efficiency is also of great importance. They are promoted comprehensively and widely. The most relevant EU directive is related to increasing energy efficiency. Directive (EU) 2023/1791 regulates the key directions that will be followed to change and improve the energy system. The key goal is the decarbonization of the energy system in two directions - the use of new green technologies and reducing the amount of energy consumed. A separate section summarizes actions in district heating (DH) systems focused on decarbonization and strengthening centralization. The focus is on network development, although production capacities can be divided into smaller ones focused on individual city districts. In addition, in order to better utilize the DH infrastructure, heat supply in winter generates synergy with cooling supply in summer. Combining these two solutions will improve the payback periods of technologies and the utilization of infrastructure.

The main problem is how, based on the EU Green Deal, to conduct an investment assessment in municipal heat production companies, providing them with opportunities not only to replace worn-out infrastructure, but also to create a basis for the use of new technologies and the implementation of activities.

The aim of the article is to assess the possibilities of regional, remote areas to transform energy systems using new and relevant technologies that correspond to prevailing international trends.

Literature review

The consequences of climate change are increasingly felt around the world. Heat waves, sudden snowfalls, floods are just some of the evidences of changing weather. One of the main reasons for this phenomenon is the pollution created by the energy system. The use of fossil fuels over the past 200 years has fundamentally changed the global environmental situation. Growing economic prosperity has fueled the growth of pollution. Due to the late concern for the environmental situation, actions to stop climate change are necessary and urgent. This coincides with the rapid level of urbanization and the deterioration of the economic and social situation of regions. The solution to both of these problems can be complex, including energy transformation activities in regional areas. The use of renewable energy resources involves the combination of various technologies in order to increase the production of green energy. This in itself creates a direction for the decentralization of the energy system, since in the case of electricity generation, the influence of centralized production sources is reduced. Energy transformation involves the combination of different technologies related to energy production and storage. At the same time, new energy production derivatives are emerging, such as cooling produced by centralized heat production facilities. One of the essential distinctive features of energy production based on renewable resources is the ability to use currently unexploited resources. This is related to the construction of wind and solar power plants on unused land areas, the use of biomass waste, and the production of biomethane from organic waste. Land resources and waste are concentrated in regions whose potential is currently not fully exploited. The use of these resources in regions would create conditions for new business activities – profitable land lease, biomass exploitation, and the provision of maintenance services. In addition, regions are characterized by unexploited electricity and gas networks, thus further promoting energy transformation.

The energy sector, including the field of heat production, has undergone significant changes in recent years. Relevant technological combinations are being sought that would allow not only to engage in core production activities but also provide a basis for new business initiatives and energy security. This is especially visible in the field of heat production - synergies with the water treatment sector are being sought, and electricity generation technologies are also being implemented. Although the heat sector is often treated as quite specific and narrow, the latest technological solutions allow the production of not only centralized heat in winter but also centralized coolness in summer. This will expand the need for managerial competencies required by a business entity, in connection with the expanding amplitude of activities and growing income levels.

Management and investment challenges in the heat generation sector include complex aspects. When analyzing the need to develop managerial competencies, it is emphasized that it is necessary to develop cybersecurity and data protection competencies (Georgiadou et al, 2023; Pirta-Dreimane et al, 2024). As energy systems become increasingly digital, with the emergence of remote-control capabilities, there is also a risk that these systems can be taken over by hostile entities. In order to avoid these risks, managerial competencies must be constantly strengthened (Karaeva & Magaril, 2025). This is inevitably related to the need for investment, since each new investment must be supported by the emergence of managerial changes. In the case of the European Union, the existing General Data Protection Regulation (GDPR) creates the need not only to strengthen the infrastructure, but also to develop data management competencies. In the case of heat generation, the necessary competencies are mainly related to customer data management (Temelkovski,

Temjanovski, 2018; Hanushchak-Yefimenko, & Arabuli, 2022). However, fundamental decisions on how to supplement the managerial competencies in the company are related to the chosen heat production method. Accordingly, the need for competencies and the possibilities of attracting them through employment contracts or purchasing relevant services must be assessed.

District heating technologies involve the use of various energy sources (biomass, solar energy, waste heat, heat pumps) in large boiler houses to efficiently produce and supply heat to building complexes, reducing pollution, increasing reliability and implementing innovative solutions, such as the integration of renewable energy, to reduce fossil fuel dependence. Key technologies and sources adapted to the Lithuanian case:

- Biomass. A local renewable resource that allows for a significant reduction in CO2 emissions compared to fossil fuels. Its trade is concentrated on the *Baltpool* energy exchange, based on which a unified Baltic biomass market has been created.
- Solar energy. The independent use of solar energy for heat production is problematic in terms of costs. Solar power plants are integrated into boiler houses, using sunlight energy for the needs of the boiler house or for heating small volumes of water (Meena et al, 2022). The use of solar energy is most effective when energy storage batteries are used. In this case, external competencies can be used for equipment maintenance by purchasing equipment maintenance services.
- Secondary energy sources. The heat released during production processes is used for heating networks. The most popular method of waste heat recovery used in Lithuania is condensing economizers, which cool the gases emitted into the atmosphere through chimneys. The use of condensing economizers is optimal when the boiler capacity reaches at least 5 megawatts (MW) (Huang et al, 2025). However, such a solution is relevant for larger areas (> 30,000 inhabitants), since a significant initial production capacity is required for the economizer to operate, which in turn requires a stable demand for heat energy.
- Heat pumps. Use ambient heat (from air, water, ground) and transfer it to the heating network in order to reduce the need for fossil fuels. In this case, it is necessary to carry out independent electricity generation activities, supplying heat pumps with the necessary amount of electricity. Heat pumps can be used as a technology that complements a centralized heat production system. Absorption heat pumps are already used in large (over 70 thousand consumers) heat supply systems.

These solutions can be universal, adaptable to municipalities of different sizes and agglomerations with a population of 5,000-500,000. However, the main challenges are recorded in municipalities with a smaller population that do not have prospects for increasing the number of heat consumers (Martinez et al, 2022). In these municipalities, maintaining infrastructure is becoming increasingly expensive, since it is impossible to take advantage of economies of scale (Reda et al, 2021). It is difficult for such municipalities to attract external financing, and existing infrastructure is used longer than its rational service life (Stec et al, 2023). Another fundamental problem is the lack of different technologies in current areas. Due to the lack of management knowledge in smaller companies, there is a risk that the wrong technological solution will be chosen, which may be either too small or too large in capacity (Świerszcz, 2023). Devices with too large a capacity may be used irrationally, and their maintenance costs may increase the price of heat. Too small facilities can create a risk of energy supply disruptions during the coldest period of the year. Currently, there is a tendency that different development situations in the heat sector are studied quite limitedly (Sayegh et al, 2017; Bush et al, 2016; Tereshchenko, & Nord, 2018; Zajacs, Borodiņecs, 2019). Energy systems of larger cities (>500,000 inhabitants) are studied based on the principle of technology integrity and the use of scale. Smaller cities lack a critical approach, good science and practical examples that would allow making responsible investment decisions. The existence of such studies would allow filling both technological and managerial gaps in making investment decisions.

For the sake of an objective assessment of future investments, an objective analysis is required, which includes not only possible current needs, but also future prospects for the development of the region. An objective assessment of the situation will allow creating a resilient infrastructure that is beneficial to the area throughout its entire period of operation. When assessing methodological aspects, it is important to emphasize that in addition to the introduction of theoretical models, it is mandatory to assess current raw material data, thus creating the opportunity to obtain objective future projections. Since in this case the example of a municipal enterprise is being assessed, it is noted that the enterprise operates in a regulated market, and the price of its final product – heat – is determined centrally based on the actual costs incurred by the enterprise. This limits the business entity's ability to unilaterally change energy prices, while at the same time establishing clear projections of investment payback.

Methodology

The analysis uses data from a municipal heat production company located in one of the Lithuanian municipalities. The company is a relatively small-sized company that has produced about 15,000 MWh of heat energy in recent years. Over the past 5 years, the volume of heat production has decreased by 25 percent due to building renovation and a lack of new customers. The existing production infrastructure is functional, but inflexible, unable to fully adapt to changes in weather

conditions and periods when full production capacity is not required. The company operates in one city, the population of which in 2025 reached 5,120. Currently, heat production is carried out based on biomass - 100 percent of it was consumed in 2025. The company also has a reserve heat production units using fuel oil and wood pellets. The main goal is to assess the possibilities of using more flexible production technologies, which would allow both energy production and expansion of the range of services.

To assess economic indicators, classic indicators recognized by state and business credit institutions are used – net present value (NPV) and internal rate of return (IRR). These indicators allow for an objective assessment of project costs and generated income throughout the entire project implementation period. The costs included in calculating NPV and IRR include annual maintenance costs, interest costs, as well as other internal and external costs. Evaluation actions will be carried out for two technologies – a cogeneration heat production facility (producing heat and electricity simultaneously) and flexible heat production systems using biomass. Possible assumptions are established for the implementation of both technologies, which will affect economic indicators and technical aspects, adapted to the analyzed case. When assessing the assumptions, the principle of skepticism is followed – exceptional price values formed due to external circumstances are not assessed, instead, using basic, conservative price values that maintain the profitability of suppliers' levels (in the case of energy prices). In the case of technology cost analysis, commercial offers and national heat market regulatory norms are evaluated. Response surface methodology analysis is used as a substantiating factor, based on existing capacities of similar size. This aim is to determine optimal and competitive energy price levels.

Biomass price component

It can be stated that since 2023, there has been a stable biomass market in Lithuania, meeting the needs of both biomass buyers and sellers. The biomass price that had prevailed until then (~11 EUR/MWh) (VERT, 2026) was determined by biomass imports from Belarus. This reduced the competitiveness of local producers, which is why almost a third of biomass producers withdrew from the sector (State Data Agency, 2026). It is generally accepted that a healthy price level for both biomass producers and heat industry companies has been established at 25 EUR/MWh. It is likely that this or a slightly lower price level will remain in the future. The increase in the price level will be influenced by seasonality, but the influence of this phenomenon will be reduced by the strategy of heat industry companies to store part of their biomass in warehouses. Figure 1. The biomass price is projected based on three scenarios, assuming that the biomass price will increase by about 3-5 percent annually.

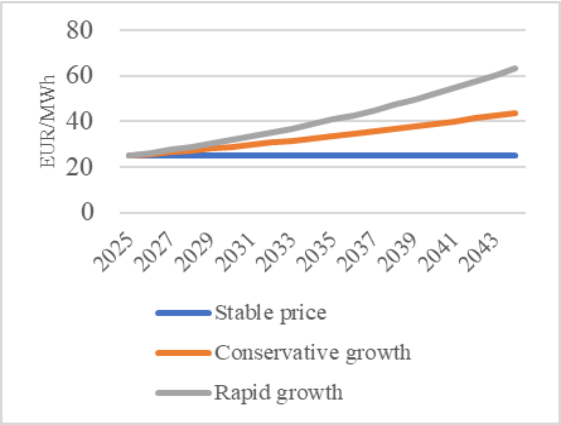


Fig. 1. Scenarios of biomass price

The average biomass price is determined according to three scenarios for a 20-year period:

- Stable scenario – EUR 25
- Conservative growth scenario – EUR 34
- Rapid growth scenario – EUR 41.

The dynamics of the price of biomass pellets is not assessed due to the fundamentally changed operating assumptions – a significant decrease in the number of local pellet producers and the resulting instability of supply and prices. From a short-term perspective, without encouraging pellet production volumes, it is necessary to change pellet-fired boilers to other technologies. There are no assumptions related to the increase in pellet production volumes in Lithuania.

Electricity price component

The electricity market is dominated by price uncertainty, determined by insufficient electricity production volumes in Lithuania. Due to the growing use of renewable resources and insufficient electricity storage capacities, price jumps are visible, which significantly increase the costs of business entities and residents. In order to generate own electricity, it is necessary to assess the fact that the peaks of electricity production and consumption in the company are essentially separated. For this purpose, it is necessary to install energy storage capacities. The electricity price trends presented in Fig. 2 are preliminary, assuming that price differences will be equalized through own electricity storage facilities. The starting point is the price of EUR 70, which indicates stability in the electricity price market.

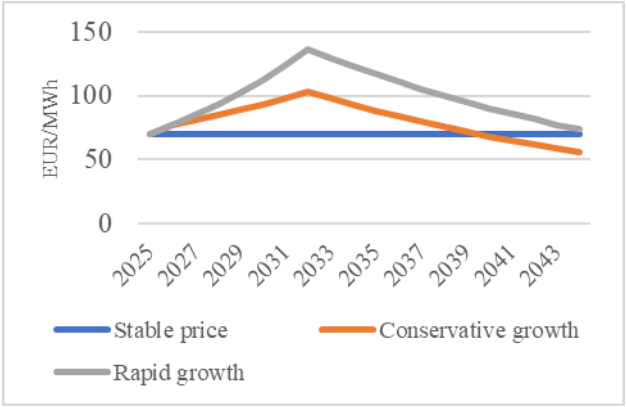


Fig. 2. Scenarios of electricity price

The following assumptions are used for further calculations:

- Until 2033, a conservative price change may reach 5% per year, a rapid change – 10% per year.
- After 2033, if the electricity production targets specified in the National Energy Independence Strategy will be achieved, a 5% decrease in electricity prices is projected in both cases.
- Hourly price changes are not evaluated due to the complexity of the process, assuming the need to have own energy storage facilities or carry out hedging transactions.

Employees and organizational structure

No significant changes in personnel are planned. The selected technology is close to the solutions currently used, which ensures that the competences accumulated in the company over many years will be properly utilized. In the case of the installation of heat pumps or solar collectors, equipment maintenance services, which will be purchased from outside, will be of great importance. The new equipment will allow for better utilization of existing employees, as it will work more efficiently due to its novelty. Due to the unchanged production mode (the company does not supply hot water), no significant changes in work organization are expected. In individual cases, some employees may contribute to the apartment building administration department at certain times, if additional work is needed.

WACC evaluation

Due to the activities of the analyzed company in a regulated market, any investments must be coordinated with national authorities. According to a pre-established methodology (Table 1), the weighted average cost of capital (WACC) is calculated, which will determine the rate of return on investments set in the company. Due to restrictions on investment returns, the WACC indicator used reflects the regulated activity environment in which the company operates.

Table 1. Indicators required for calculating WACC in the case of a heat production company (VERT, 2026)

Indicator	Value
Return on equity (R_e) for renewable energy	7,846 proc.
Debt share (WD) (optimal capital structure)	50 proc.
Equity share (WE) (optimal capital structure)	50 proc.
Corporate tax rate (m)	0,17
Risk-free rate of return (R_f)	3,546 proc.
Equity risk premium (R_{erp})	5 proc.
Relative risk measure (weighted β) for renewable energy	0,860
Cost of equity	8,270
WACC	**7,125**

Table 2 sets out the technical assumptions, which include biomass utilization technologies. In both cases, commercial offers were received to justify the price, focused on the energy requirements of the analyzed company. The variable costs presented in the table are related to the operation and maintenance costs of the equipment. They can increase or decrease depending on the prevailing equipment maintenance policy and the distribution of responsibilities in the company.

Table 2. Technical assumptions for the assessment of heat and electricity generation facilities

	Investment, EUR/kWh (heat)	**Variable costs, EUR/MWh**	**Number of commercial offers**
Biomass cogeneration plant	1000	20	2
Biomass cogeneration plant for heat production (with economizer)	750	15	3
	Investment, EUR/kWh (electricity)	**Variable costs, EUR/MWh**	**Number of commercial offers**
Biomass cogeneration plant	500	5	2

Results and discussion

First, the use of cogeneration solutions is analyzed. This would allow the company to expand its activities - both heat and electricity would be produced at the same time. Such a solution is mainly applied in agglomerated areas with a constant need for heat. At the moment, when heat energy can be converted into centralized cooling, the cogeneration solution can significantly affect the production and economic results of a business entity.

When evaluating cogeneration technology in the context of this research, it can be stated that this step is limited by the optimal capacity of the equipment and compatibility with the city's energy system. During cogeneration, heat is produced, and electricity is obtained as waste energy. In the case of the analyzed company, the active production phase is limited to the heating season (October-April), since hot water supply is not carried out. Due to the lack of industrial enterprises, the possibility of supplying heat energy during the summer period is limited. When evaluating these aspects, it can be stated that such a power plant could operate effectively for about 6 months. per year. To determine the optimal price and production capacity, the Response surface methodology is used, with the help of which different operating parameters will be studied in the case of cogeneration power plants. Heat production facilities (3.6 and 9 MW of heat capacity) available on the market, which can also produce electricity (1,2,3 MW of electricity capacity), are used for the assessment. The statistical calculations presented in Table 3 show the suitability of the model for further research. The independent variables are heat and electricity capacity indicators, and the dependent variable is the heat price.

Table 3. Initial information for the heat and electricity capacity and heat price model

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	4,38	2	2,19	21,75	0,0002	Significant
A-Heat price	2,94	1	2,94	29,17	0,0003	
B-Electricity price	0,0315	1	0,0315	0,3130	0,5882	
Residual	1,01	10	0,1008			
Lack of Fit	0,2628	4	0,0657	0,5291	0,7200	Non-significant
Pure Error	0,7450	6	0,1242			
Correlation Total	5,39	12				

Table 4 presents statistical calculations of heat and electricity capacity and electricity cost in cogeneration power plants. The axis of cost assessment is the currently acceptable biomass price level - 25 EUR/MWh. With the growth of biomass prices, the cost level may significantly change in the direction of increasing electricity prices. During the analysis, a trend was observed that low-power boilers are the most uncompetitive in terms of electricity prices. The electricity produced in them is characterized by a high cost and low production volume. After considering balancing and other network fees, the profitability of such power plants is even lower.

Table 4. Diagnostics of the heat and electricity capacity and electricity and heat price model

Std. Dev.	0,3175	**R²**	0,9531
Mean	7,84	**Adjusted R²**	0,9357
C.V. %	4,05	**Predicted R²**	0,9195
		Adeq Precision	11,9231

According to the analysis performed, the average price of heat and electricity in cogeneration power plants is determined. When evaluating the smallest cogeneration power plants available on the market, it was assumed that the most efficient of them generate 9 MW of heat and 2 MW of electricity. This allowed determining the optimal price of heat and produced electricity, which can be obtained using cogeneration facilities. Table 5 shows that at a biomass price of 25 EUR/MWh, heat can be produced at a high level of competitiveness, but the price of electricity produced, compared to other production methods, is uncompetitive. Considering that in the case of the analyzed business entity, the optimal power of the heat boiler is half that of the boiler, the solution of a cogeneration solution based on the use of biomass is economically unreasonable. As the price of biomass rises, the price of electricity will grow even more, therefore the competitiveness of the electricity produced in the market would be limited.

Table 5. Optimal energy prices for heat and electricity capacity and electricity and heat price model

Analysis	Optimal point
Heat price	7,96031
Electricity price	9,61149

In order to maintain the stability of the analyzed heat production company's operations and create conditions for more flexible energy production, the possibilities of using the analyzed integrated biomass power plant with an economizer are further analyzed. It is emphasized that according to EU directives, when installing new biomass boilers, at least 105 percent of the useful operating coefficients must be achieved, as well as conservative pollution standards must be met. This ensures that investments will be directed at the latest technological solutions that will allow for efficient production of heat energy while minimizing pollution. The price of biomass used in the calculations is presented in Table 6. The optimal 15-year payback period is assessed.

Table 6. Biomass price scenarios for biomass power plant payback calculations

Year	Stable price	Average price	Higher price
2025	25	25	25
2026	25	25,8	26,3
2027	25	26,5	27,6
2028	25	27,3	28,9
2029	25	28,1	30,4
2030	25	29,0	31,9
2031	25	29,9	33,5
2032	25	30,7	35,2
2033	25	31,7	36,9
2034	25	32,6	38,8
2035	25	33,6	40,7
2036	25	34,6	42,8
2037	25	35,6	44,9
2038	25	36,7	47,1
2039	25	37,8	49,5

Other conditions:

- Estimated biomass boiler capacity – 2.95 MW,
- 25 percent grant regime applied/not applied,
- Municipal support not foreseen,
- WACC applied – 7.125 percent

To assess economic indicators, classic indicators recognized by state and business credit institutions are used – net present value (NPV) and internal rate of return (IRR). These indicators allow an objective assessment of project costs and generated income throughout the entire project implementation period. Table 7 presents preliminary calculations, which were made considering the assumption that the national development bank ILTE will allocate part of the funds required for the installation

of the boiler house in the form of a grant. The costs included in calculating NPV and IRR include annual maintenance costs, interest costs, as well as other internal and external costs.

Table 7. Economic evaluation indicators of the installation of a new biomass power plant with an economizer are analyzed in the DH system of the company

Indicator	Value	Stable price	Average price	Higher price
Nominal power of new heating boiler, MW	2,95			
Investment amount, million EUR	2,6			
Amount of possible non-refundable grant, million EUR	0,6			
Net present value, EUR (without grant)		-22822	162590	339436
Internal rate of return, % (without grant)		6,94	8,25	9,36
Net present value, EUR (with grant)		395646	581058	757904
Internal rate of return, % (with grant)		10,19	11,71	12,75

In this case, the methods chosen allowed for a comprehensive assessment of individual technologies. In case of doubts about the feasibility of cogeneration technology in smaller areas, the decision was made to conduct a preliminary assessment based on Response Surface Methodology (RSM). Having obtained the result that the heat price after the investment would be twice as high as the current one, the decision was made not to propose this technology for further assessment. The application of RSM in energy is currently quite rare, since it is based on traditional investment assessment tools, and in addition, such an assessment requires more data. The analysis conducted by Ahmed et al (2025) showed that there are different methods for assessing energy investments, but RSM is not mentioned among them. In this case, the focus is on cost-benefit analysis methods that show payback periods, but in-depth forecasts describing the efficiency of the selected technology are avoided. The application of RSM can expand the understanding of energy system assessment methods, thus making investment actions more responsible.

When analyzing scientific literature, it is found that energy projects are evaluated mainly through the prism of costs. This is done for two reasons. First, it is related to growing pollution taxes. Second, in the case of the energy business, revenues can be difficult to predict due to trading on the open market (Björnebo et al, 2018). However, such an approach is not suitable for renewable energy systems, since in their case pollution taxes are not relevant, and in addition, revenues can be forecast based on different scenarios. They must include aspects related to the price dynamics of the last 5 years, as well as price shocks that occurred at that time. This will allow maintaining objectivity, while creating conditions for more accurate determination of the payback period of investments.

Another aspect that unites existing energy system research is a narrow approach and the limitations of the use of existing methodological solutions. There is a lack of universal models that would allow for a comprehensive assessment of energy systems of different sizes, since currently either large, agglomerated energy systems are assessed, or rural energy systems that operate in small communities. In the latter case, the cost component is particularly emphasized when large energy systems are analyzed for opportunities to generate higher income (Hendricks et al, 2016). The article prepared by the research group has formed a universal methodology, while simultaneously analyzing medium-sized regional areas located in municipal centers. This achieves a large assessment coverage, creates a comparable assessment base, while maintaining the universality of the model.

Energy system conversion studies, which simultaneously assess the economic and management components, will be relevant in the future, as climate change will dictate the conditions for large-scale changes. Medium-sized energy system conversion studies are important in that the transformation of these territories can stimulate positive changes on a national scale, especially in larger areas. At the same time, changes can bring positive shifts in business management - attracting new specialists, changing management methods, thus in turn increasing financial results, reputation level and economic power.

Conclusions

The prevailing legal regulation in the heat production sector is no longer limited to the modernization of heating systems alone. Strategic importance is also given to energy efficiency initiatives, which will significantly affect the income of companies in the heat sector. In the case analyzed, the decrease in income may be programmed not only by the pace of urban development, but also by the expanding energy efficiency initiatives among the company's consumers. European Union legal acts are implemented in Lithuania through the Law on the Heat Industry of the Republic of Lithuania and the National Energy Independence Strategy. The latter envisages an important role for the heat sector in strengthening the energy system of the entire country and increasing local electricity consumption. This concerns both the promotion of cogeneration solutions and the introduction of new technologies, such as heat pumps, into energy systems.

The company under analysis has been using local renewable biomass as the main source of heat production

for many years. This has allowed the company to ensure stable and low heat prices for the residents of the serviced area. However, the approaching end of the service life of the company's heat production facilities creates financial and technological challenges. The need to choose flexible production technologies and find adequate financing solutions creates a trend of uncertainty in operations. Delayed investments can lead to growing maintenance costs, but the search for favorable financing sources is a key factor in the success of the modernization of the infrastructure of the company under analysis. In order to find optimal modernization solutions that would increase the efficiency of the company's operations, a technical-economic assessment is necessary, while taking into account the changing dynamics of heat consumption in the analyzed area during the strategic period.

When assessing the necessity of installing a new heating boiler, it should be stated that the cogeneration solution is inappropriate for the analyzed case. The main reasons are related to the insufficient cogeneration capacity (3 MW of heat output instead of the required at least 9 MW) and the intermittent operation of the boiler house (the boiler house operates only during the heating season). Investments in cogeneration technology would be excessive and would not bring economic benefits to either the company or consumers. The installation of a heat pump should be considered as a factor increasing the flexibility of the heating system, but for this it is necessary to develop integrated electricity management solutions – own production and storage capacities.

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PROJECT INTEGRATION GOVERNANCE FOR MANAGING FRAGMENTATION IN HYBRID ENVIRONMENTS

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Abstract
Contemporary project environments increasingly combine specialized digital platforms, decentralized teams, hybrid project-management methods and multi-level governance arrangements. Although such heterogeneity can strengthen flexibility and local adaptation, it also increases the need for integration. Existing project-management research examines complexity, hybrid methodologies, information overload, knowledge transfer and governance, but these streams provide only a partial explanation of the cumulative coordination problem created when tools, information, methods, knowledge and decision rights are insufficiently connected. The purpose of this study is to conceptualize project management fragmentation (PMF) as a multidimensional integration problem and to propose a Project Integration Governance framework for limiting its dysfunctional effects while preserving useful flexibility. An exploratory qualitative expert survey was administered during April–May 2026. The analytical sample comprised 12 experienced project-management professionals with 7–18 years of experience, predominantly from service-intensive sectors. Open-text responses were analyzed through deductive-inductive thematic coding and cross-case comparison. Five recurring dimensions of PMF were identified: tool and system fragmentation, data and information fragmentation, methodological fragmentation, knowledge fragmentation, and governance and decision-right fragmentation. Coordination-related costs represented the most recurrent consequence (11 of 12 expert accounts), while data and information fragmentation was reported by 10 experts, tool/system fragmentation by 9, methodological fragmentation by 7, knowledge fragmentation by 8, and governance/responsibility fragmentation by 8. Decision latency and rework were repeatedly reported as downstream effects. The findings suggest that heterogeneity is not equivalent to fragmentation. Fragmentation emerges when the integration capacity of a project environment becomes insufficient relative to the heterogeneity that must be coordinated. On this basis, Project Integration Governance is proposed as a cross-cutting response comprising information, technological, methodological, knowledge and governance integration. The study further develops the principle of Minimum Viable Standardization: organizations should standardize the interfaces necessary for coherence - authoritative information sources, common data definitions, decision rights and escalation rules - while retaining flexibility in team-level working practices and specialized tools. The study contributes a theoretically grounded framework for explaining how fragmented project environments generate coordination overload and provides practical guidance for PMOs, programme managers and governance designers. The proposed causal pathway is interpretive rather than statistically tested and should be validated in larger quantitative and cross-sector studies.

KEY WORDS: project management fragmentation, project integration governance, hybrid project management, project governance, coordination, digital transformation.
JEL classification: M10, M15, O33

Introduction

Contemporary project management increasingly takes place within heterogeneous organizational environments. Project teams simultaneously use specialized task-management platforms, collaboration applications, document repositories, enterprise systems, spreadsheets and client-specific reporting solutions. At the same time, project delivery increasingly combines Agile, predictive and organization-specific governance practices, while decision-making is distributed across project managers, product owners, functional managers, sponsors, risk functions and steering committees. Each of these elements may individually support effective project delivery; collectively, however, they generate substantial requirements for integration.

Digital transformation has intensified this development. Digital technologies can increase organizational responsiveness, transparency and analytical capability, but successful transformation depends on the integration of technologies with organizational processes, structures and competences rather than on technology adoption alone (Parviainen et al., 2017; Mergel et al., 2019; Chen et al., 2025). Recent research further demonstrates that project management offices themselves operate as boundary-spanning actors during digital transformation, facing tensions between established governance arrangements and emerging digital practices (Simard and Aubry, 2025).

A related transformation concerns the widespread use of hybrid project-management approaches. Empirical studies show that Agile and predictive practices increasingly coexist rather than function as mutually exclusive alternatives (Gemino et al., 2021; Marnewick and Marnewick, 2023). Systematic reviews similarly indicate that practical knowledge concerning successful implementation of hybrid project management remains dispersed and context-dependent (Reiff and Schlegel, 2022; Székely et al., 2025). Recent research on customized hybrid methodologies demonstrates that effective hybridization depends on deliberate integration of practices according to project context rather than mechanical combination of methods (Mirzaei et al., 2025). Studies of Agile-hybrid implementation also identify organizational misalignment, unclear processes and insufficient integration between organizational objectives and project practices as recurring challenges (Sithambaram et al., 2021).

Existing project-management scholarship nevertheless approaches the resulting coordination problem through

several largely distinct research streams. Project-complexity research examines differentiation, interdependence, uncertainty and the management difficulties associated with complex project structures (Baccarini, 1996; Vidal and Marle, 2008; Bjorvatn and Wald, 2018). Information-overload research focuses primarily on situations in which information-processing demands exceed individual or organizational processing capacity (Eppler and Mengis, 2004). Project-governance research considers the allocation of authority, accountability and governance structures (Too and Weaver, 2014; Müller et al., 2016). Knowledge-management research addresses the difficulties of retaining and transferring knowledge between temporary projects and permanent organizations (Disterer, 2002; Schindler and Eppler, 2003; Prado and Sapsed, 2016; Barbosa et al., 2022). Studies of virtual project teams further emphasize communication, collaboration technologies and knowledge-sharing challenges in digitally mediated environments (Swart et al., 2022).

The present study argues that these perspectives illuminate different parts of a broader integration problem. The existence of multiple tools, methodologies, actors or information sources does not necessarily constitute a management failure. Heterogeneity may increase flexibility, specialization and adaptability. A problem arises when the interfaces between heterogeneous elements are insufficiently integrated, causing project actors to spend excessive effort reconciling information, translating between management processes, clarifying authority and reconstructing fragmented knowledge.

Recent work on systems integration in project networks provides evidence that project performance depends on several complementary integration mechanisms, including systems, knowledge, relational, governance and process integration (Lei, 2025). However, the project-management literature has paid less attention to the inverse condition: how insufficient integration across several internal project-management dimensions accumulates into a distinct pattern of fragmentation, and where the boundary lies between productive heterogeneity and dysfunctional fragmentation.

The scientific problem addressed in this study is therefore formulated as follows: *how does insufficient integration among heterogeneous project-management elements create fragmentation, through which mechanisms does this fragmentation affect project coordination and performance, and which governance mechanisms can mitigate its negative consequences without eliminating beneficial flexibility?*

Three research questions guide the study:

RQ1: What dimensions characterize project management fragmentation in digital and hybrid project environments?

RQ2: Through which mechanisms does project management fragmentation affect coordination, decision-making and project performance?

RQ3: Which Project Integration Governance mechanisms can mitigate dysfunctional fragmentation while preserving beneficial project flexibility?

The research object is contemporary project management in digital and hybrid organizational environments. The research subject comprises the dimensions, manifestations, consequences and integration mechanisms associated with project management fragmentation.

The purpose of the study is to conceptualize project management fragmentation in digital and hybrid project environments and to propose an integration governance framework explaining its dimensions, consequences and mitigation mechanisms.

The objectives are to distinguish project management fragmentation from related project-management concepts; identify its principal dimensions through theoretical and expert evidence; explain the mechanisms through which fragmentation influences project coordination and decision-making; and formulate governance principles capable of reducing dysfunctional fragmentation without unnecessarily restricting project-level flexibility.

The study uses an exploratory qualitative expert-survey design and thematic cross-case analysis. Its theoretical contribution is twofold. First, project management fragmentation is conceptualized as a multidimensional integration problem rather than as a synonym for project complexity or digital-tool proliferation. Second, the study develops the proposition that productive heterogeneity becomes dysfunctional fragmentation when integration capacity becomes insufficient relative to the diversity that must be coordinated. The practical contribution consists of a Project Integration Governance framework and the associated principle of Minimum Viable Standardization.

Theoretical background

Digital and hybrid project environments

Digital transformation changes both the technological infrastructure and the organizational conditions under which projects are managed. Digitalization is not simply the conversion of analogue processes into digital formats; it involves changes to processes, organizational structures, stakeholder relationships and managerial practices (Mergel et al., 2019). Project management therefore increasingly operates through interconnected technological and organizational systems.

A recent systematic review of digital transformation in project management identifies the integration of digital technologies into project processes and organizational routines as an important emerging research area (Chen et al., 2025). At the organizational level, the benefits of digitalization depend on the coordinated transformation of processes, data, competences and organizational structures (Parviainen et al., 2017). This means that additional digital capabilities simultaneously generate additional integration requirements.

The same principle applies to hybrid project management. Hybrid approaches combine Agile and predictive practices in order to exploit complementary benefits rather than adhere to a single methodological logic (Gemino et al., 2021; Reiff and Schlegel, 2022). Their use has become increasingly established in project practice (Marnewick and Marnewick, 2023). More recent studies demonstrate that successful hybridization requires context-specific configuration and active management of interfaces between methodologies (Mirzaei et al., 2025; Székely et al., 2025).

Consequently, methodological plurality should not itself be interpreted as fragmentation. Hybrid management becomes problematic when different planning cycles, reporting requirements, roles and governance routines coexist without explicit mechanisms for synchronization.

Fragmentation and integration in project management

Integration has long been recognized as central to managing project complexity. Baccarini's observation that "project complexity can be defined in terms of differentiation and interdependency" and is managed through integration remains particularly relevant to contemporary project environments (Baccarini, 1996, 201). Project complexity therefore provides an important starting point, but complexity and fragmentation should not be treated as equivalent.

Project complexity describes characteristics such as multiplicity, differentiation, interdependence, uncertainty and dynamic interaction (Baccarini, 1996; Vidal and Marle, 2008). Empirical evidence indicates that complexity can adversely affect schedule and cost performance when project-team capabilities are insufficient to absorb it (Bjorvatn and Wald, 2018). Fragmentation, in contrast, concerns the quality of connections between elements that already exist within the project-management environment.

Project Integration Management similarly emphasizes the need to coordinate project processes and activities (Project Management Institute, 2017). The concept examined in this study is broader in a different direction: it concerns fragmentation across the socio-technical project-management architecture, including digital systems, information structures, methodologies, organizational knowledge and decision authority.

Information fragmentation also differs from information overload. Information overload occurs when the volume or complexity of information exceeds available processing capacity (Eppler and Mengis, 2004). Fragmentation may occur even when the total information volume is manageable, for example when several systems contain incompatible versions of project status or when it is unclear which source is authoritative.

Based on these distinctions, "Project management fragmentation (PMF)" is defined in this study as: "*the condition in which heterogeneous project-management elements are insufficiently integrated, generating additional coordination, information-processing and governance costs and reducing the ability of project actors to maintain coherent project understanding, decision-making and control".*

This definition conceptualizes fragmentation as a relational condition. Multiple systems or methodologies are not fragmented merely because they are different; fragmentation emerges when the connections needed to coordinate their differences are inadequate.

Organizational information processing and coordination

Organizational Information Processing Theory provides the main theoretical explanation for this distinction. Galbraith (1974) proposed that organizational design must align information-processing capacity with the information-processing requirements generated by uncertainty and interdependence. Tushman and Nadler (1978) similarly emphasized that organizational differentiation increases the need for integrating mechanisms.

Applied to projects, increasing heterogeneity expands integration requirements. More systems create more data interfaces; more specialized actors create more coordination interfaces; hybrid methodologies create more process interfaces; and distributed decision authority creates more governance interfaces. When organizational integration capacity grows at a slower rate than these requirements, fragmentation can occur.

Coordination Theory complements this explanation. Malone and Crowston (1994) conceptualised coordination as the management of dependencies between activities. Fragmented project environments increase the number or difficulty of dependencies requiring active management. Examples include reconciling duplicated data, translating between reporting structures, synchronising Agile delivery cycles with predictive governance cycles and clarifying overlapping decision rights.

Knowledge integration represents a related challenge. The knowledge-based view conceptualises organizations as mechanisms for integrating specialized knowledge distributed among individuals (Grant, 1996). This requirement is especially pronounced in project-based organizations because projects are temporary organizational forms and their dissolution creates risks of knowledge discontinuity (Turner and Müller, 2003). Project-learning research repeatedly demonstrates that knowledge is difficult to capture, retain and transfer across project boundaries (Disterer, 2002; Schindler and Eppler, 2003; Prado and Sapsed, 2016; Barbosa et al., 2022).

From heterogeneity to dysfunctional fragmentation

Heterogeneity can be valuable. Specialized knowledge, differentiated technological tools and adaptable methodologies can increase local effectiveness. Organizational ambidexterity similarly depends on maintaining differentiated activities while preserving sufficient integration at organizational level (O'Reilly and Tushman, 2008).

The key distinction proposed here is therefore: *Heterogeneity + sufficient integration → flexibility and adaptability,* whereas: *Heterogeneity + insufficient integration → dysfunctional fragmentation.*

This formulation implies an integration-capacity boundary rather than a fixed numerical threshold. As heterogeneity increases, the mechanisms connecting diverse project-management elements must become sufficiently capable to preserve coherent action.

This perspective also explains why complete standardization is unlikely to represent an optimal solution. Eliminating heterogeneous systems or methodologies may reduce integration requirements, but it may also eliminate specialized capabilities and contextual adaptability. The relevant management question is therefore not how to maximize standardization, but which interfaces must be standardized or integrated to preserve coherence.

The present study uses the term “Minimum Viable Standardization” to describe this principle: organizations establish the minimum mandatory standards required for cross-project coherence while retaining local flexibility where variation creates value.

Research methods

Research design

An exploratory qualitative research design was used to investigate how experienced project-management professionals perceive and experience fragmentation in digital and hybrid project environments. A qualitative design was selected because the study aims primarily to clarify the boundaries, dimensions and mechanisms of an emerging conceptual phenomenon rather than estimate its prevalence in a defined population.

The empirical study was conducted through a qualitative expert survey administered during April and May 2026. The survey was designed to capture professional accounts of fragmented project-management practices, their perceived causes and consequences, and organizational mechanisms used to mitigate them.

The qualitative approach is consistent with the objective of developing and refining concepts from information-rich expert evidence (Patton, 2015). The textual responses were analyzed using thematic principles derived from Braun and Clarke (2006).

Sample composition and adequacy

The final analytical sample comprised 12 project-management professionals with between 7 and 18 years of project-management experience (Table 1). Respondents held senior roles including Senior Project Manager, Program Manager, Head of PMO, Portfolio Manager, Agile Delivery Manager, Transformation Project Manager and Delivery Manager.

The sample was predominantly service-oriented. Ten of the twelve respondents represented service-sector organizations, including IT services, consulting, financial services, shared services, SaaS, professional services, logistics, marketing and creative services, insurance and IT outsourcing. The remaining respondents represented telecommunications and public/administrative services, both characterized by substantial project-based activity.

The study did not use statistical sample-size calculation because the purpose was qualitative conceptual exploration rather than population-level inference. Sample adequacy was considered in relation to the specificity of the respondents' expertise, the diversity of represented project contexts and the recurrence of thematic patterns across cases. This logic is consistent with the principle that qualitative sample adequacy depends on the information richness of the material rather than statistical power alone (Malterud et al., 2016). No claim of statistical representativeness is made.

Table 1. Profile of project management experts

Expert	Sector	PM experience	Position / role	Organization type
E1	IT services	14 years	Senior Project Manager	International company
E2	Consulting services	11 years	Program Manager	Consulting company
E3	Financial services	16 years	Head of PMO	Bank
E4	Business services centre	9 years	Project Manager	Shared services organization
E5	Telecommunications	13 years	Portfolio Manager	Large enterprise
E6	IT / SaaS	8 years	Agile Delivery Manager	Technology company
E7	Professional services	18 years	PMO / Transformation Lead	International company
E8	Logistics services	12 years	Project Manager	Logistics company
E9	Marketing / creative services	7 years	Project Lead	Agency
E10	Insurance services	15 years	Transformation Project Manager	Insurance company
E11	IT outsourcing	10 years	Delivery Manager	Service company
E12	Public / administrative services	17 years	Program Manager	Large organization

Data collection

The expert survey was administered during April and May 2026. The qualitative component invited respondents to describe their experience of fragmentation within contemporary project environments, including problems related to project-management tools and systems, information and reporting, coexistence of different management methodologies, project knowledge, governance and decision rights.

Respondents were also asked to identify perceived causes and consequences of fragmentation and practices they considered effective for reducing it. Particular attention was paid to coordination effort, delays in decision-making, duplicated work, information inconsistency and the balance between standardization and project-team flexibility.

The survey was structured to avoid defining fragmentation too narrowly in advance. This allowed respondents to identify fragmentation according to their own project-management experience while simultaneously addressing dimensions derived from the theoretical review.

Respondents are anonymized in the article using codes E1–E12, and organizational names are not disclosed.

The survey was distributed online via Google Docs during April–May 2026. Fifteen project management experts from Lithuania were invited to participate, and 12 completed responses were included in the analysis. The questionnaire was administered in Lithuanian. Informed consent was obtained at the beginning of the survey,

where participants were informed about the purpose of the study, voluntary participation, confidentiality and the use of anonymized responses for scientific research.

Data analysis

The textual survey material was analyzed using a deductive-inductive thematic approach. The analysis proceeded through four main stages.

First, all responses were reviewed to identify recurring descriptions of project-management fragmentation, its causes, consequences and possible solutions. Second, an initial coding structure was informed by the theoretical literature on project integration, complexity, information processing, project governance and knowledge management. Third, additional codes were retained where patterns emerged from the expert material that were not adequately represented by the initial theoretical categories. Finally, cross-case comparison was used to aggregate related codes into higher-order themes.

Five higher-order fragmentation dimensions emerged from this process: tool/system fragmentation, data/information fragmentation, methodological fragmentation, knowledge fragmentation and governance/decision-right fragmentation. Consequence codes were subsequently organized around coordination overload, information inconsistency, governance ambiguity, decision latency, rework and knowledge loss. Proposed solutions were grouped under information, technological, methodological, knowledge and governance integration.

A cross-case matrix was used to record whether each theme was substantively represented in each expert account. Theme frequencies therefore indicate recurrence across cases, not statistical prevalence in the wider population. No inferential statistical interpretation is attached to the reported counts.

Results and discussion

Project management fragmentation as an integration problem

The most important cross-case finding was that respondents did not define fragmentation simply by the presence of multiple tools, methodologies or organizational actors. Rather, fragmentation was associated with inadequate connections between these elements.

E7 provided the clearest illustration of this distinction by emphasizing that several project-management tools can coexist without creating significant difficulties when information moves reliably between them. Problems arise when data must be manually reconciled or when project actors cannot determine which source reflects the current project situation.

This finding supports the theoretical distinction between heterogeneity and fragmentation. Heterogeneity describes diversity within the project-management environment. Fragmentation describes the dysfunctional condition that emerges when this diversity creates integration demands that the available organizational mechanisms cannot adequately handle.

This interpretation is consistent with Organizational Information Processing Theory (Galbraith, 1974; Tushman and Nadler, 1978) and Coordination Theory (Malone and Crowston, 1994). It also refines the project-complexity perspective: differentiation and interdependence produce a need for integration, but the empirical findings indicate that the quality of integration itself deserves explicit analytical attention.

Five principal dimensions of PMF emerged from the expert evidence.

Tool and system fragmentation

Tool and system fragmentation was represented in 9 of 12 expert accounts. E1 described an environment in which Jira, Microsoft Teams, SharePoint, Excel and an internal financial system were used simultaneously. Different platforms could contain different representations of project status, requiring the project manager to spend substantial time reconciling information.

E11 identified a related inter-organizational manifestation. The outsourcing provider and client maintained separate systems, resulting in duplicate project representations and additional effort to transfer and transform reporting information.

These findings reinforce the broader digital-transformation argument that technology adoption creates value only when organizational processes and information structures are adequately integrated (Parviainen et al., 2017; Chen et al., 2025). They also correspond with recent systems-integration research identifying technical and process integration as important components of project-network performance (Lei, 2025).

The empirical evidence nevertheless suggests an important qualification: the number of systems should not be used as a proxy for fragmentation. Several specialized tools may be appropriate. Fragmentation arises where interoperability, system ownership and information-governance arrangements are insufficient.

Data and information fragmentation

Data and information fragmentation was the most frequently reported PMF dimension, occurring in 10 of 12 cases.

E5 described inconsistent KPI definitions and reporting formats across organizational units, including situations in which apparently identical indicators were calculated differently. E9 highlighted a related communication problem: project tasks and agreements could simultaneously appear in e-mail, collaboration tools, project systems and verbal communication, creating uncertainty over which representation should be treated as authoritative.

Information fragmentation therefore differs from conventional information overload. Eppler and Mengis (2004) focus primarily on excessive information-processing demands; the expert evidence in this study shows that substantial costs may also emerge from inconsistency and ambiguity between sources, even when the total information volume is not excessive.

Nine experts identified or implied the need for a single source of truth. However, the results indicate that this should be understood primarily as a governance principle rather than a demand for one universal application. Different systems may remain authoritative for different data

domains provided that ownership, synchronization and reporting rules are explicit.

Methodological fragmentation

Methodological fragmentation was identified in 7 of 12 expert accounts.

E2 described a consulting project in which the client required stage-gate governance, the consulting organization followed Agile principles and the delivery team used Scrum. These arrangements produced parallel management processes and separate governance artefacts.

E10 reported a similar pattern in insurance transformation projects. Delivery was iterative, while budgeting, risk management and formal approval processes remained predictive, resulting in planning and governance cycles operating at different speeds.

These findings are consistent with research demonstrating the widespread coexistence of Agile and predictive practices (Gemino et al., 2021; Marnewick and Marnewick, 2023) and with studies documenting implementation challenges within Agile-hybrid projects (Sithambaram et al., 2021). They also support the conclusion of Reiff and Schlegel (2022) and Székely et al. (2025) that organizational implementation of hybrid project management remains incompletely understood.

However, the expert evidence does not support the conclusion that hybrid approaches themselves are problematic. Instead, it reinforces more recent arguments for deliberate customization and integration of project-management methodologies (Mirzaei et al., 2025). Methodological fragmentation therefore appears to be primarily an interface-design problem: different methodologies create dysfunction when their planning cycles, responsibilities, reporting requirements and decision processes are not explicitly connected.

Knowledge fragmentation

Knowledge fragmentation appeared in 8 of 12 accounts.

E4 described project knowledge distributed across meeting notes, private documents, collaboration messages and individual employees' tacit knowledge. When team composition changed, contextual understanding and the rationale behind earlier decisions could be lost.

This finding corresponds with long-standing research on the difficulty of transferring learning from temporary projects into organizational memory (Disterer, 2002; Schindler and Eppler, 2003). More recent research similarly demonstrates that project-based organizations require active mechanisms for the acquisition, retention and retrieval of corporate memory (Barbosa et al., 2022).

The current evidence suggests that knowledge fragmentation should be distinguished from data fragmentation. Data fragmentation concerns incompatible or distributed formal representations. Knowledge fragmentation concerns the dispersion of contextual understanding, experiential expertise and decision rationale. These resources are particularly important in project-based organizations, where temporary organizational structures can interrupt continuity between people and projects (Turner and Müller, 2003; Prado and Sapsed, 2016).

Digital collaboration does not automatically solve this problem. Virtual project-team research demonstrates that communication technologies can support knowledge sharing but also require appropriate practices, guidelines and organizational conditions (Swart et al., 2022).

Governance and decision-right fragmentation

Governance and decision-right fragmentation was identified in 8 of 12 expert accounts.

E3 described overlapping decision rights among the project manager, product owner, IT management, risk function and steering committee. This overlap increased escalation and extended decision time.

E12 highlighted a related responsibility-authority mismatch. Project managers could be formally accountable for project outcomes while important decisions remained under the authority of functional managers.

The findings are consistent with project-governance research distinguishing governance structures from day-to-day project management and emphasizing the importance of clearly designed authority and accountability arrangements (Too and Weaver, 2014; Müller et al., 2016).

The additional contribution of the PMF perspective lies in treating governance ambiguity as interconnected with other forms of fragmentation. Decision ambiguity becomes more damaging when decision-makers simultaneously face inconsistent information, competing methodological processes or fragmented knowledge.

Coordination overload, decision latency and rework

The strongest cross-case consequence was increased coordination effort, reported in 11 of 12 expert accounts.

Reported forms of additional coordination included reconciliation of information between systems, duplication of reporting, additional meetings, clarification of responsibilities, translation of information between departments and synchronization between supplier and client environments.

This pattern directly supports the coordination-theoretic logic that performance depends on the mechanisms used to manage dependencies (Malone and Crowston, 1994). Fragmentation increases the effort required to manage those dependencies.

The findings therefore suggest that the principal relationship may not be a simple direct effect of fragmentation on project performance. Instead, PMF appears to generate coordination overload, which consumes managerial attention and project resources that could otherwise be devoted to delivery and adaptation.

Decision latency was reported in 8 cases and appeared to emerge through two closely related mechanisms. Information inconsistency requires actors to determine which data are trustworthy before making decisions, while governance ambiguity requires them to determine who has authority to decide. When both conditions occur simultaneously, escalation and reconsideration are more likely.

Rework was identified in **7 cases**. It included repeated data entry, duplicated reporting, corrections caused by

outdated information and decisions revisited because different stakeholders relied on different project representations.

The current qualitative evidence supports this sequence as a conceptual explanation, not as statistically demonstrated causality.

Dimensions and management responses

Table 2. Dimensions and manifestations of project management fragmentation

PMF dimension	Typical manifestations	Main mechanism	Potential consequence	Integration response
Tool/system fragmentation	Multiple disconnected platforms; parallel status representations; manual reconciliation	Coordination overload	Duplicated effort; inconsistent reporting; reduced transparency	System interoperability; explicit systems of record; automated data exchange
Data/information fragmentation	Competing project statuses; inconsistent KPIs; multiple communication channels	Information inconsistency	Decision delay; reduced confidence; rework	Authoritative information governance; common data definitions; single-source-of-truth principle
Methodological fragmentation	Parallel Agile, predictive and custom processes; different planning cadences	Coordination overload and governance ambiguity	Governance tension; duplicated reporting; role confusion	Explicit methodology interfaces; aligned governance cycles
Knowledge fragmentation	Knowledge dispersed across people, messages and documents	Knowledge discontinuity	Knowledge loss; repeated mistakes; weak organizational learning	Knowledge repositories; decision logs; transition and lessons-learned procedures
Governance/decision-right fragmentation	Overlapping authority; responsibility without authority; unclear functional boundaries	Governance ambiguity	Decision latency; escalation; reduced agility	Decision-right matrices; responsibility-authority alignment; explicit escalation mechanisms

Source: developed by the author based on expert survey findings and relevant literature (Baccarini, 1996; Too & Weaver, 2014; Gemino et al., 2021; Barbosa et al., 2022; Chen et al., 2025).

The cross-case recurrence of themes is summarized in Table 3.

Table 3. Cross-case thematic findings

Theme	Experts mentioning theme (n=12)
Tool/system fragmentation	9
Data and information fragmentation	10
Methodological fragmentation	7
Knowledge fragmentation	8
Governance/responsibility fragmentation	8
Increased coordination costs	11
Decision latency	8
Rework	7
Need for a single source of truth	9
Need for clearer governance	8
Integrated data/systems	9
Partial rather than full standardization	6

These frequencies should be interpreted as indicators of thematic recurrence rather than estimates of prevalence.

From beneficial heterogeneity to dysfunctional fragmentation

An important finding concerns the boundary between flexibility and fragmentation.

The respondents did not generally consider multiple tools, methodologies or decentralized arrangements inherently dysfunctional. E6 explicitly described the benefits of allowing project teams to choose tools and practices appropriate to their work. The problem emerged as such autonomy expanded without corresponding organization-level integration mechanisms.

This pattern suggests a flexibility paradox. Increasing autonomy can improve local adaptation while simultaneously increasing organization-wide integration requirements. Once integration capacity becomes insufficient, the same diversity that previously supported flexibility begins to generate coordination costs.

Six respondents explicitly favored partial rather than complete standardization. This empirical pattern supports the principle labelled here as Minimum Viable Standardization.

Rather than prescribing one methodology or platform for all projects, the principle identifies a limited set of organizational interfaces that should remain common. These may include authoritative information sources, core data definitions, KPI logic, decision rights, escalation rules and minimum knowledge-retention requirements.

Project teams can retain greater autonomy concerning specialized delivery tools, team-level routines and context-specific working practices.

This interpretation is compatible with organizational ambidexterity, which emphasizes the need to maintain differentiation without losing organizational coherence (O'Reilly and Tushman, 2008), and with recent hybrid-project research emphasizing contextual configuration rather than one universal methodology (Mirzaei et al., 2025).

Project Integration Governance

The management responses proposed by respondents converge into what this study terms “Project Integration Governance”. Project Integration Governance is defined as: “*the coordinated set of information, technological, methodological, knowledge and decision-governance mechanisms through which an organization maintains coherence among heterogeneous project-management elements while preserving appropriate project-level flexi-*

bility". Five integration domains correspond to the five fragmentation dimensions.

1. Information integration establishes authoritative data ownership, common definitions, consistent KPIs and clear systems of record.

2. Technological integration addresses interoperability, automated data exchange and unnecessary duplication between digital platforms.

3. Methodological integration establishes explicit interfaces between Agile, predictive and organization-specific processes, including aligned reporting, planning and escalation cycles.

4. Knowledge integration creates mechanisms for retaining project rationale and experience through decision logs, knowledge repositories, lessons-learned processes and structured personnel transitions.

5. Governance integration aligns decision authority with accountability and establishes explicit boundaries among project managers, sponsors, steering committees, product roles and functional management.

These mechanisms can be interpreted through Organizational Information Processing Theory as ways of increasing integration capacity to meet growing information-processing requirements.

The proposed framework is presented in Fig. 1.

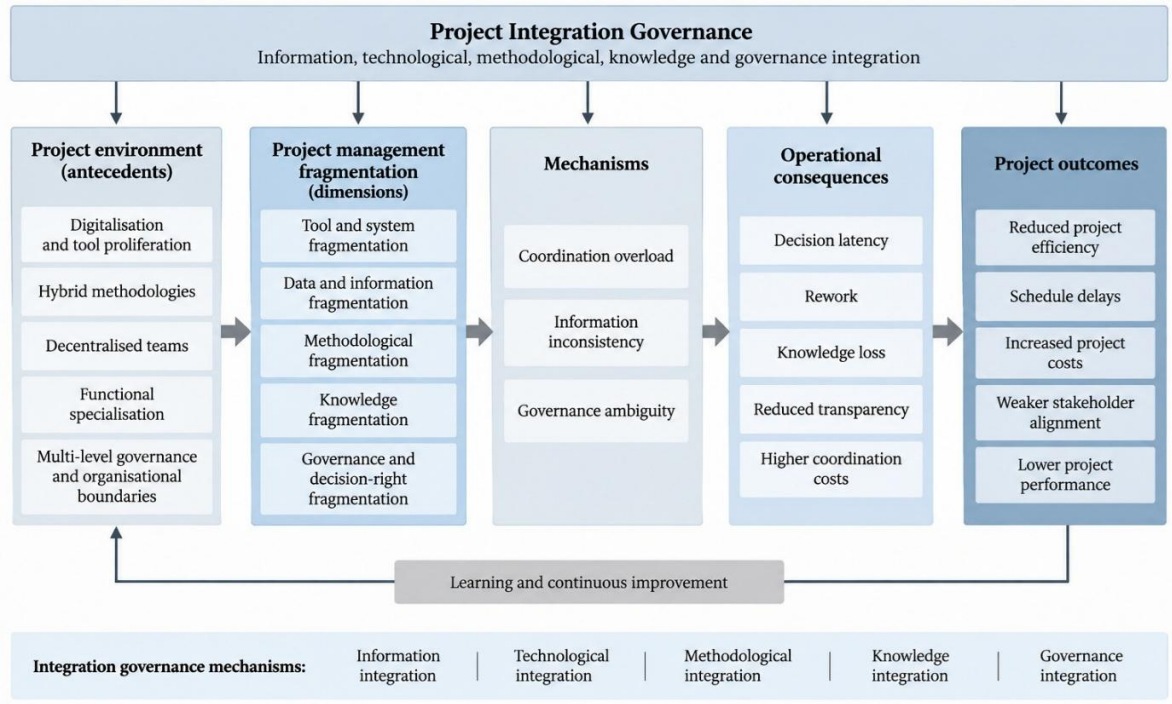


Fig. 1. Project management fragmentation and integration governance framework

The framework should not be interpreted as a statistically validated causal model. Rather, it synthesizes recurring expert patterns with established theoretical mechanisms and provides propositions for subsequent quantitative testing.

Managerial implications

The findings suggest that organizations should not treat fragmentation solely as an IT rationalization problem. Reducing the number of project-management applications may help, but consolidation alone will not resolve fragmented decision rights, incompatible methodologies or dispersed project knowledge.

A more comprehensive managerial response can be organized into five steps.

First, organizations should diagnose fragmentation across systems, information, methodologies, knowledge and governance rather than assess only software architecture.

Second, they should identify the interfaces where fragmentation generates the greatest coordination cost. These may be data transfers between systems, handovers between Agile teams and steering committees, or decisions requiring repeated escalation.

Third, organizations should define minimum mandatory integration standards, including authoritative information sources, common data definitions and decision-right structures.

Fourth, critical interfaces should be strengthened through interoperability, aligned governance cycles, knowledge-retention practices and responsibility-authority alignment.

Finally, organizations should deliberately preserve local flexibility in domains where variation continues to generate project value.

Project Integration Governance therefore seeks integration without unnecessary uniformity.

Conclusions

The study provides evidence that project management fragmentation in contemporary digital and hybrid environments is best understood as an integration problem rather than simply as technological proliferation or project complexity.

In response to RQ1, five recurring dimensions were identified: tool and system fragmentation (9 of 12 expert accounts), data and information fragmentation (10 of 12), methodological fragmentation (7 of 12), knowledge fragmentation (8 of 12), and governance and decision-right fragmentation (8 of 12). Their coexistence indicates that fragmentation extends beyond any single technological or organizational component.

In response to RQ2, the strongest recurring mechanism was increased coordination effort, reported in 11 of 12 expert accounts. Information inconsistency and governance ambiguity further contributed to decision latency, while repeated reconciliation and incompatible project representations generated rework. The findings therefore support an interpretive pathway in which fragmentation increases coordination and information-processing requirements before affecting project-level outcomes.

In response to RQ3, the study proposes Project Integration Governance as a cross-dimensional management response. Its five components: information, technological, methodological, knowledge and governance integration - they correspond to the five observed dimensions of fragmentation.

The principal theoretical contribution lies in distinguishing heterogeneity from fragmentation. Multiple methodologies, technologies and organizational actors may remain beneficial where adequate integration exists. Dysfunctional fragmentation emerges when integration capacity becomes insufficient relative to the heterogeneity that must be coordinated. The proposed integration-capacity boundary extends existing project-complexity, information-processing and hybrid-management perspectives by making the quality of interfaces between heterogeneous project-management elements the primary analytical focus.

The principle of Minimum Viable Standardization translates this argument into managerial practice. Rather than choosing between unrestricted decentralisation and comprehensive standardization, organizations should standardize those interfaces required for coherent project management while preserving variation that supports specialized work and local adaptation.

Limitations

The study has several limitations. The analytical sample is small and purposively focused on experienced professionals, with strong representation of service-sector organizations. The study captures managerial perceptions at one point in time and therefore cannot demonstrate causal relationships or the longitudinal development of fragmentation. Theme frequencies describe recurrence within the sample and should not be interpreted as estimates for a wider population. The conceptual framework consequently requires further empirical validation.

Future research should develop and validate a Project Management Fragmentation measurement instrument covering the five proposed dimensions. Larger quantitative studies could test the relationships between PMF, coordination overload, decision latency, rework and project performance using structural equation modelling. Longitudinal research could further investigate whether investment in Project Integration Governance reduces fragmentation as organizations mature. Finally, emerging AI-based project-management systems deserve particular attention because they may simultaneously improve cross-system information integration and introduce additional technologies, decision actors and accountability interfaces.

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Alongside project management, her research addresses broader management challenges related to organizational change, innovation, digitalization and sustainable development. Particular attention is given to the ways in which organizations design and improve governance arrangements, integrate information and knowledge, coordinate cross-functional activities and adapt management practices to changing technological and institutional conditions. Her work is therefore positioned at the intersection of project management, organizational management and innovation, with an emphasis on both theoretical development and practical applicability.

A recurring theme in her research is the search for management approaches that help organizations remain coherent and effective without reducing the flexibility needed for innovation, adaptation and professional autonomy. She is interested in how digital transformation, hybrid management practices, distributed responsibilities and multiple organizational interfaces influence coordination, decision-making and performance. Her research also explores how governance and integration mechanisms can support knowledge sharing, organizational learning and more effective collaboration among stakeholders.

Her professional and academic experience allows her to approach management problems from both strategic and operational perspectives. By combining research on project governance, organizational integration, innovation and sustainable development with practical experience in project implementation and leadership, she contributes to the development of management solutions suited to complex and changing organizational environments. Her current academic interests also include the long-term development of organizational capabilities that support resilience, innovation and sustainable performance.

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The submitted articles must be original, previously unpublished. It is prohibited to publish the articles of this journal in other publications.

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2. **Abstract** with the main words in the language of the article. The Abstract should briefly cover the contents of the article; specify the aspect of how the problem will be analyzed. The text of the Abstract must be clear and concise. **The Abstract must contain about 3000 characters**.
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Web documents

Lee, D. Y., Sun, B., Wilson, A., & Sarvas, G. (2024). Increasing Electric Vehicle Adoption Among Disadvantaged Populations: A Case Study in Los Angeles. *OSTI OAI (U.S. Department of Energy Office of Scientific and Technical Information)*. [Retrieved March 18, 2026], https://www.osti.gov/biblio/2478604.

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