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FOREWORD

Presented number of Silesian University of Technology. Scientific Papers. Organization and Management Series. Presented papers contain result of researches conducted by various universities. The number consists of 36 papers.

The papers presented in the number concentrate on many topics connected with organization and management. There are in the number papers about: environmental management; economics; quality management; logistics; the usage of artificial intelligence in management; social security; entrepreneurship; sustainable development; quality of life; innovation management; service management; strategic management; ESG in management; smart city; project management and CSR.

Radosław Wolniak

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LEVERAGING ECOLOGICAL TAXES AND CIRCULARITY FOR A "GREEN" RECOVERY OF THE UKRAINIAN COMMUNITIES

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Purpose: the primary objective is to synthesize global empirical evidence to formulate strategic recommendations for optimizing Ukraine's ecological taxation framework, thereby accelerating a sustainable, climate-resilient green recovery across Ukrainian communities.
Design/methodology/approach: the study achieves its objectives by deploying the long-term economic forecasting models alongside structural analyses of localized institutional frameworks, resource allocation mechanisms, and environmental policies necessary for decentralized municipal reconstruction.
Findings: the paper finds that while Ukrainian communities exhibit remarkable grassroots resilience, severe infrastructure destruction and fiscal constraints require the urgent implementation of market-based ecological taxes and circularity to catalyze localized green investments in the rebuild process.
Research limitations/implications: the primary limitation of the paper stems from the extreme unpredictability of the ongoing war in Ukraine, which complicates long-term localized planning and limits the availability of real-time environmental data required to assess community-level ecological impacts.
Social implications: the social implications of this paper indicate that embedding circular economy frameworks into municipal reconstruction will generate equitable green employment, thereby elevating public well-being across Ukrainian communities.
Originality/value: the originality of this paper lies in its novel synthesis of international empirical evidence on environmental taxation and its targeted application to the decentralized, post-war green recovery of Ukrainian municipalities, offering an unprecedented policy blueprint for national legislators, local authorities, and international donors seeking to leverage fiscal instruments for circular, community-led reconstruction.
Keywords: carbon taxation, circular economy, decarbonization, resource efficiency, sustainable development.
Category of the paper: Conceptual paper.

1. Introduction

The global “green” transition toward sustainable future is currently advancing into a critical implementation phase, necessitating innovative policy instruments and strategic frameworks. The contemporary challenge lies in operationalizing actionable pathways that accelerate the systemic phase-out of fossil fuels while simultaneously reinforcing energy security, economic competitiveness and sustainable development paradigms. In this context, the Roadmap for Transitioning Away from Fossil Fuels (TAFF), initiated by the COP 30 Brazilian Presidency and substantiated by the International Renewable Energy Agency (IRENA, 2026), functions as a foundational platform for delineating trajectories commensurate with multifaceted climate, security, and socio-economic exigencies.

Mitigating hydrocarbon reliance demands a multi-faceted paradigm encompassing regulatory updates, policy innovations, institutional reforms, infrastructural modernization, and robust international financing mechanisms. This systemic paradigm shift requires a fundamental reconfiguration of both the production and consumption of energy services globally. Crucial interventions include the exponential expansion of renewable power generation capacity, pervasive electrification across key end-use sectors (namely transportation, industry, and the built environment), augmented energy efficiency protocols, the modernization of grid and storage infrastructure, and the widespread commercial deployment of sustainable fuels. In Ukraine, where the ongoing war creates additional challenges for the development of all sectors of economy, the economic prospects for increasing the share of renewable energy sources include a number of advantages, in particular, reducing dependence on energy imports and increasing energy and economic security (Korchyha, 2026).

These global “green” transition frameworks hold acute, practical relevance for the post-war “green” recovery of Ukrainian communities. To successfully operationalize these national strategies at the municipal level, Ukraine must utilize environmental taxes to drive a circular economy approach directly within local communities. Currently, the circular economy sector in Ukraine is assessed by experts as very low or non-existent, with circularity remaining mostly in the planning phases and confined primarily to basic waste management concepts.

The reform of ecological taxes in Ukraine is currently undergoing a massive structural transformation aimed at integrating the nation's environmental policies with the European Union standards and facilitating a post-war green recovery. As of 2026, the country is shifting from a fragmented environmental tax system toward a comprehensive, market-based carbon pricing mechanism.

The urgency of this domestic reform is heavily driven by the European Union's Carbon Border Adjustment Mechanism (CBAM), which officially began full operations on January 1, 2026. Starting in 2027, Ukrainian exporters to the EU must annually report and pay for the carbon emissions generated during the previous year. To mitigate the financial impact on

domestic businesses, the new draft ETS law allows Ukrainian exporters to make voluntary carbon border adjustment contributions directly to the national Modernization Fund.

It is assumed that the implementation of an effectively calibrated, market-based ecological tax framework, specifically the transition to a national Emissions Trading System ETS (Cabinet of Ministers order, 2025) and the strict ring-fencing of environmental revenues for local Modernization Funds will act as a primary economic catalyst for the Green Recovery of war-affected Ukrainian communities, significantly accelerating the integration of circular economy models, resource upcycling, and sustainable municipal infrastructure. At the same time it is predicted that gradual increasing of ecological taxes will stimulate Ukrainian enterprises and households to introduce ecologically friendly solutions and circular technologies.

To establish a rigorous epistemological foundation for this investigation, the introductory framework is organized around a highly structured matrix of objectives: (i) identification of the research gap; (ii) formulation of the primary research question; (iii) definition of the explicit purpose of the article; (iv) delineation of intermediate objectives; (v) statement of testable assumptions and hypotheses; and (vi) specification of the overarching research method.

The primary research gap stems from a systematic literature review indicating that while environmental taxation is thoroughly evaluated within stable market economies, its operationalization within decentralized, war-affected regions undergoing active reconstruction remains unexplored. According to what we were able to find, there are no studies referring and reporting on the direct integration of global empirical carbon pricing frameworks with localized circular economy models specifically tailored for the post-war recovery of Ukrainian communities. This study bridges this gap, establishing its practical and theoretical significance.

Research question: How can market-based ecological taxes be systematically integrated to drive a sustainable, decentralized green recovery within war-torn Ukrainian municipalities?

Purpose of the article: The primary purpose is to synthesize international empirical evidence on ecological taxation and translate these insights into an actionable policy blueprint for Ukraine's community-led green recovery.

Intermediate objectives:

1. To evaluate the long-term impacts of pollutant pricing on corporate behavior in developed nations.
2. To identify the specific mechanisms through which environmental levies influence corporate research and development (R&D) and institutional absorptive capacity.
3. To present data of several Ukrainian regions with effective implementation of green transition.
4. To formulate targeted, decentralized fiscal mechanisms for ecological taxes and green public procurement across Ukrainian communities.

Assumptions and Hypotheses:

H1: The implementation of a calibrated, market-based carbon tax and national Emissions Trading System (ETS) in Ukraine will incentivize domestic enterprises to expand their internal absorptive capacity for clean technologies without inducing severe industrial decline.

H2: The strict ring fencing of ecological tax revenues for localized municipal Modernization Funds will successfully mitigate the fiscal constraints of war-affected Ukrainian communities, directly accelerating community-level circular reconstruction.

Research method: the research method deployed relies on a comparative macro-level policy synthesis and structural simulation, linking validated OECD empirical patterns with current Ukrainian institutional and regional data.

2. Literature review

With Europe tightening carbon-pricing rules while mobilizing hundreds of billions of Euro for sustainable infrastructure and circular economy transition, researchers (Martinsson et al., 2024) suggest emissions taxes can spur firms to invest in the technical know-how needed for cleaner production, even when they do not produce breakthrough green inventions. The central achievement of the study is proving that a substantial carbon tax directly causes significant reductions in firm-level carbon emissions without severely penalizing economic performance. The authors demonstrate that targeted firms achieved meaningful decarbonization while maintaining their output, sales growth, and productivity.

In "The Macroeconomic Impact of Europe's Carbon Taxes", Gilbert E. Metcalf and James H. Stock (2023) deliver a crucial, data-driven assessment of the macroeconomic consequences of carbon pricing. By analyzing a multi-decade panel dataset across European Union countries that implemented carbon taxes prior to the mid-2010s, the authors provide much-needed empirical clarity to a debate often dominated by highly theoretical and pessimistic modeling. By showing that historical European carbon taxes successfully reduced emissions while leaving macroeconomies stable and unharmed, the paper offers strong justification for adopting carbon pricing as a core, economically safe pillar of international climate mitigation strategies.

Podolchuk’s scientific research (Podolchuk, 2023) concludes that the EU ETS functions as far more than a passive environmental policy; it is a dynamic economic engine driving the structural transition toward European energy independence. The paper provides an essential reference framework for transitional economies—including Ukraine—demonstrating how robust carbon market mechanisms can be synchronized with national regulatory policies to accelerate grid decarbonization and support sustainable economic regulation.

A long-running debate in climate policy is whether environmental taxes simply raise costs for firms or whether they also encourage cleaner technological change.

3. Methods

The methodology of this study is primarily declarative and conceptual, functioning as a comparative policy synthesis rather than an independent econometric regression of raw primary datasets. This research summarizes, evaluates, and critically extrapolates the empirical findings, statistical analysis of the macro-level OECD panel data, patent metrics from PATSTAT, and corporate financial records from Compustat originally established and published by Brown, Martinsson, and Thomann (2022).

The author's independent analytical contribution consists of synthesizing these international baseline mechanisms — specifically temporal asymmetry, corporate absorptive capacity, and high-knowledge-spillover dynamics—and mapping them against Ukraine's contemporary institutional landscape. To perform this contextual application, the author aggregates public macro-environmental data from the Cabinet of Ministers of Ukraine, CAIT, and the IEA to construct a simulated model of an effective carbon rate (ECR) profile. Furthermore, a comparative fiscal analysis is deployed to benchmark Ukraine's historical environmental tax revenue-to-expenditure ratios against European counterparts. Finally, this structural framework is applied directly to the operational realities of Ukrainian communities, evaluating a policy transition from traditional least-cost public procurement to a circularity-driven recovery paradigm.

4. Results

The imposition of stringent greenhouse gas (GHG) emission taxes has been empirically linked to significant expansions in corporate research and development (R&D) expenditures, alongside the accelerated integration of circular economy paradigms. Notably, the impact of such environmental levies on R&D investment is disproportionately pronounced within industries reliant on highly polluting production technologies; this differential response strongly supports a causal relationship between pollution taxation and technological adaptation (table 1), as documented in the foundational literature compiled by Brown et al. (2022) and the Stockholm School of Economics (2022).

Interestingly, while emission taxes stimulate R&D spending, they do not correspond with a concurrent increase in patenting activities among high-emission enterprises. This divergence suggests that affected corporations primarily allocate R&D resources toward enhancing their "absorptive capacity"—the ability to assimilate, operationalize, and deploy external environmental knowledge—rather than generating new, patentable innovations. Corroborating this mechanism, the strategic shift toward R&D and circular economy practices in response to pollution taxation is predominantly concentrated in sectors characterized by high knowledge spillovers, where external technological insights are more readily accessible and acquired (Stockholm School of Economics, 2022).

Table 1.
Taxonomy of environmental taxation strategies and implementation trajectories across selected OECD countries (1990-2012).

Tax Implementation Strategy	Represented countries (1990-2012)	Macroeconomic Policy Pattern Observed
Aggressive / Rapid Scaling	Denmark, South Korea	Sharp transition from zero taxation to maximum index levels (0 to 6).
High Baseline Stability	Japan	Consistent maintenance of high baseline taxation across the timeline.
Moderate / Incremental Scaling	France, Italy, Spain	Gradual upward adjustment; critical inflection point identified between 1997-2001.
Minimal or Non-Taxation Baseline	Australia, Canada, Germany, United Kingdom	Minimal active pricing or complete absence of active SOx levies (10 sample nations).

*Note: Table synthesized by the author to organize the visual parameters of the OECD dataset distribution.

An analysis of the provided Table 1 reveals distinct patterns in how developed economies operationalize environmental taxation. There is no universal consensus on the magnitude or speed of environmental taxation. Approaches range from aggressive, rapid implementation (e.g., Denmark and Korea spiking from 0 to 6) and consistently high baseline taxation (Japan) to moderate, incremental scaling (France, Italy, Spain) or minimal taxation (Australia, Canada). The period between 1997 and 2001 represents a critical inflection point. Almost all the nations that transitioned from zero taxation to an active SOx tax did so during this specific macroeconomic window. Once established, emission taxes are rarely rescinded or significantly reduced. Countries generally maintain or increase their tax levels over time, indicating that such policies provide a stable, long-term regulatory environment. As noted in the study's parameters, a substantial portion of the sample (10 nations, including major economies like Germany and the United Kingdom) chose not to implement a SOx tax during this period, highlighting inconsistencies in international pollutant pricing strategies.

Utilizing a comprehensive dataset spanning 18 OECD nations from 1990 to 2012, (Martinsson et al., 2022) demonstrate that the imposition of sulfur oxide (SOx) emission taxes significantly stimulated corporate research and development (R&D) expenditure within the manufacturing sector (Figure 1).

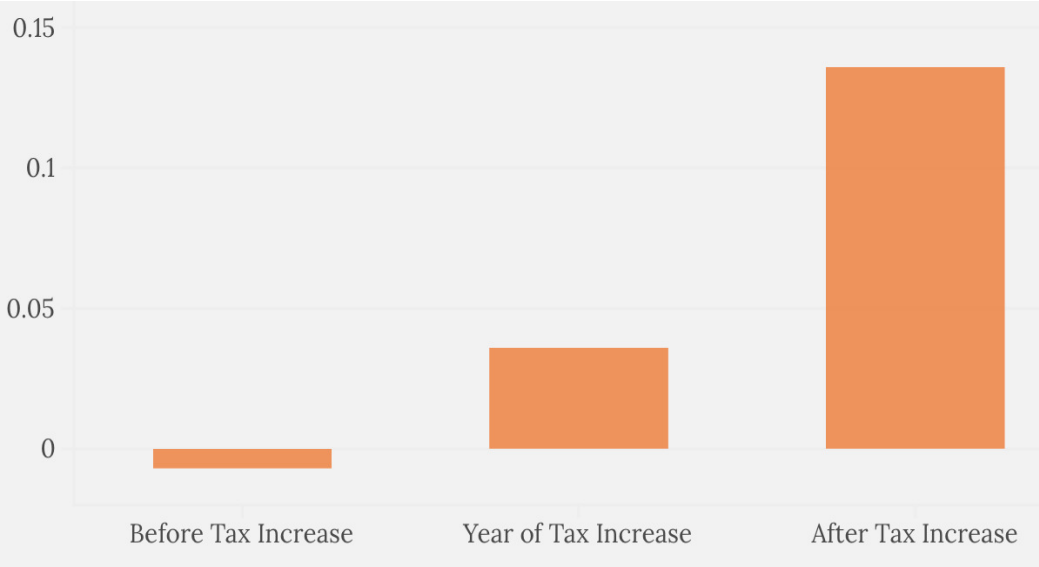

Figure 1. Estimated change in research and development spending. (Only the post-tax increase in R&D is statistically significant; estimates before and during the tax increase fall within the study's margin of error).

Source: Brown, Martinsson, Thomann, 2022.

This surge in R&D investment was predominantly concentrated in heavily polluting industries — specifically cement, chemical production, metallurgy, and petroleum refinement — characterized by high-emission production processes. The authors posit that environmental levies fundamentally alter the cost structure for these firms, rendering the continued reliance on legacy, emission-intensive technologies economically unviable.

Methodologically, the study integrates macro-level OECD pollution tax data with micro-level corporate R&D expenditures derived from Compustat, alongside global patent metrics sourced from the European Patent Office's PATSTAT database.

The empirical findings reveal economically substantial impacts:

- a one-standard-deviation escalation in pollution taxes correlated with an approximate 11% increase in mean R&D expenditure,
- the discrete introduction or elevation of such taxes yielded an even more pronounced effect, driving an average R&D spending increase of 13% to 14%,
- manufacturing entities exhibited a 13% increase in R&D outlays exclusively post-intervention.

This temporal asymmetry – whereby significant R&D expansion manifests solely following the tax implementation, with pre-intervention estimates remaining within the statistical margin of error – substantiates a causal interpretation that the policy shift directly induced the corporate response (Brown et al., 2022).

While contemporary discourse on green industrial policy frequently emphasizes inventions, this research highlights a critical, albeit less visible, mechanism. Paradoxically, despite augmented R&D expenditures, the most heavily taxed, high-pollution firms did not exhibit a commensurate increase in patenting activity.

The authors attribute this divergence to investments directed toward enhancing absorptive capacity — the organizational ability to identify, assimilate, and exploit external knowledge and technologies. Consequently, the R&D response was most acute in sectors characterized by accessible external knowledge spillovers. Firms effectively prioritized the internal expertise requisite for modernizing operations and adopting externally developed clean technologies over the generation of proprietary, breakthrough inventions. Crucially, this behavioral shift permeated beyond traditionally innovative enterprises, compelling even corporations with negligible patent histories to elevate their R&D commitments.

From a financial market perspective, these adaptive R&D investments were appraised positively. The marginal value of R&D capital appreciated significantly under regimes of heightened pollution taxation, indicating investor confidence that such expenditures would bolster long-term competitive advantage and ensure compliance with increasingly stringent environmental standards.

For regulatory bodies, these findings reinforce the efficacy of market-based environmental instruments. Beyond mere compliance, taxation architectures actively incentivize the technological investments necessary for systemic production overhauls and source-level emission reductions.

While the authors acknowledge a methodological limitation — the inability to directly quantify corresponding emission reductions due to the absence of standardized, cross-national firm-level emissions data—ancillary research provides compelling contextual evidence. In a parallel longitudinal study of the Swedish market (Martinsson et al., 2022), estimated that carbon pricing mechanisms were responsible for a minimum of one-third of observed emission reductions between 1991 and 2015, averting a counterfactual scenario wherein emissions would have been approximately 30% higher.

So, in the turbulent world a sufficiently high carbon price — even an imperfect one — should attract investments in green industrial investments. However, the decisions of these investors might in themselves also be imperfect, potentially postponing investments. One crucial factor is uncertainty and how it interacts with the irreversible nature of investments. That’s why beyond emission trading scheme design, complementary policies targeting specific sectors or technologies — such as sector-specific decarbonisation targets or direct technology support — may be warranted to address observed delays in low-carbon technology adoption, though the appropriateness of such instruments remains contingent on underlying techno-economic conditions and sector-specific contexts (Hoogsteyn et al., 2026).

5. Discussions

Regarding Ukraine, the country achieved one of the largest reductions in greenhouse gas (GHG) emissions globally, of 76% between 1990 and 2022 and was approaching its 2030 emissions reduction target prior to 2022 (United Nations Climate Change, 2024) This reduction in part reflects the drop and change in economic activity. Relative to GDP, Ukraine's emissions are among the highest globally (Climate Action Tracker, 2021), reflecting very low emission prices, alongside subsidised energy costs that reduced incentives to improve energy efficiency. Greenhouse gas emission tax rates are the equivalent of less than one USD per tonne of CO_2, and about 50% of emissions are priced, mostly via fuel excise and carbon taxes (illustrated as the lighter blue areas in Figure 2). While military actions have generated significant emissions, the war has damaged or destroyed many of the largest sources of Ukraine's emitters of emissions, such as coal-fuelled steel plants and thermal power plants (Bulman et al., 2025).

The recovery and reconstruction give a renewed impetus to modernise Ukraine's industry and infrastructure, ensuring that it is adapted to the projected effects of climate change and achieves the emissions reductions objectives. Ukraine is committed to ensuring that the reconstruction and recovery lead to more sustainable investments and circular activity, both through regulatory reform and developing taxes and incentives. For example, its estimates of the costs of reconstruction account for adaptation and reducing emissions.

The government has adopted a National Waste Management Plan through to 2033 (Roadmap of the National Waste Management Plan until 2033, 2024) and has a roadmap for creating a National Environmental Fund over 2025-2027 with the goal of building a new system of environmental taxes. Ensuring that these many plans turn into concrete actions implemented early in the reconstruction, informed by international experience, can provide greater certainty to investors and ensure investments improve the economy's environmental sustainability. Ukraine plans to align emission prices with the European Union through an emission trading scheme (ETS), combined with higher taxes for emission sources not included in the ETS. Ukraine has adopted an action plan for developing its national ETS, with the first operational phase to be start in 2028 (Cabinet of Ministers of Ukraine, 2025). It will raise coverage of industry emissions to 87% and the price towards international targets (the green areas in Figure 2 illustrate the simulated likely coverage of the planned emission trading scheme). Not implementing this price could subject exports to the European carbon border adjustment mechanism. To limit the welfare costs for vulnerable households, the scheme could use some of the revenue generated to provide well-targeted income transfers that offset some of the increase in costs, building on policies that Ukraine implemented for the energy price adjustments in the late 2010s.

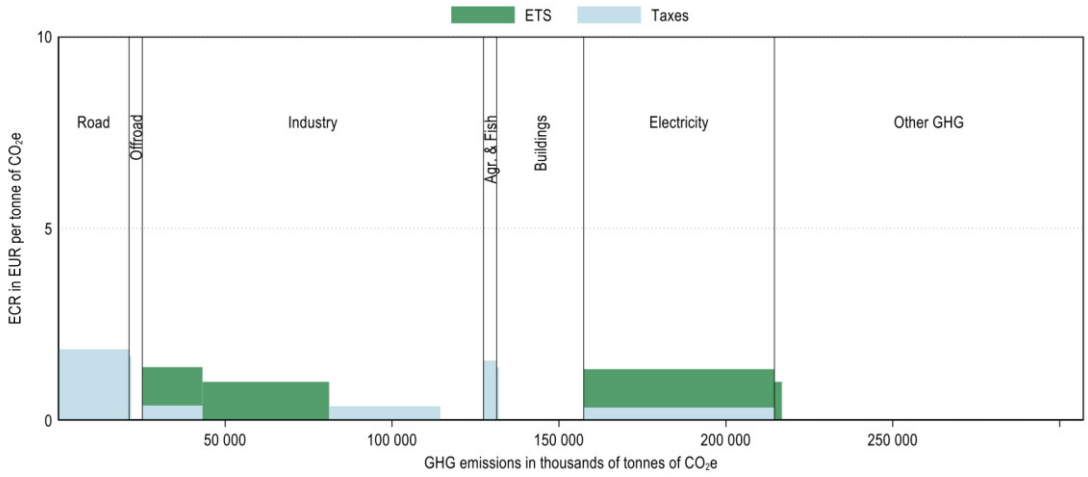

Figure 2. Modelling of the Ukraine effective carbon rate (ECR) profile if its emission trading scheme were in place in 2021.

Source: OECD estimates of coverage using information from the Cabinet of Ministers of Ukraine (2020). Other GHG emissions data are from CAIT (Climate Watch, 2022), data on CO2 emissions from energy use are based on the IEA World Energy Balances (IEA, 2023).

Ukraine plans to expand its emission trading scheme and to raise its low carbon prices. Similarly, implementing well-designed prices on pollution and other environmentally damaging activity can limit damages while encouraging polluters to adapt their operations in the most cost-effective and circular manner. Existing environmental taxes are significant, but they could more coherently support environmental policy objectives (Neuweg et al., 2023). Eliminating subsidies or reduced tax rates for environmentally damaging items, is a first step. In addition, Ukraine could consider imposing excise taxes on fertilisers or manure that would damage the soil quality or groundwater, as in the Flemish region of Belgium (OECD, 2020). Complying with environmental tax requirements would be easier for businesses if the different administering bodies aligned their approaches. Building cooperation and information exchanges between the tax authorities and the State Environmental Inspection would help improve consistency (Neuweg et al., 2021).

Circular economy development is crucial for the Ukrainian recovery and it has to be implemented for the entire product life cycle – from design and manufacturing to consumption, repair, reuse, recycling and return of resources to the economy. Currently, the life cycle of many consumer products is too short, they cannot be reused, repaired or recycled, or they are intended for single use only. It will lead to the shortage of GHG emissions.

Regarding public procurement, it is worth noting that the main drawback was considered to be the selection of the cheapest offer without taking into account other criteria. That is, more environmentally friendly goods, services or technologies did not have the opportunity to "defeat" products manufactured using "environmentally dirty" technologies. Through the implementation of a new procurement policy based on the circularity, the public sector has the opportunity to have a real impact on resource conservation, reducing environmental pollution

and preventing climate change, stimulating investments in the production of more environmentally friendly goods, services and technologies.

Despite the important legislation that is in force, it has not yet crystallized in Ukraine as a whole. Experts assess the state of development of the "circular" economy sectors themselves in Ukraine as very low or non-existent. Given that the priority issue for the closed-loop economy is waste management, "circularity" is currently only in the plans.

An important issue is to encourage the Ukrainian government to use more targeted economic instruments, namely an environmental tax, to support "circular" measures. It is worth noting that the revenues from the environmental tax in Ukraine are lower than in neighboring member states, and in terms of euros they are significantly decreasing in dynamics. This is explained by the fact that various types of environmental taxes that can be levied in EU countries partially coincide with the components of the environmental tax in Ukraine, and despite this, EU environmental taxes include such types of taxes as transport taxes and rents for the special use of forest resources, water, subsoil use, etc. Another problematic issue arises in the ratio of environmental tax revenues to state expenditures on environmental protection. In all European countries, except Ukraine, environmental tax revenues are significantly higher than state expenditures on environmental protection measures. Taking European countries as an example, France, the UK, Spain and Italy allocate a significant part of their environmental spending to waste management. In Germany and Poland, this area of environmental protection accounts for up to 20% of spending (OECD, 2022).

To ground these international insights within the specific geopolitical reality of Ukraine, a comparative examination of regional vulnerabilities and municipal fiscal capacities across Ukrainian oblasts is required. Highly industrialized and war-affected regions such as Dnipropetrovsk, Kharkiv, Zaporizhzhia, and the de-occupied territories of Kyiv and Chernihiv oblasts face disproportionate infrastructure destruction paired with legacy, carbon-intensive manufacturing profiles. Conversely, western regions including Lviv and Ivano-Frankivsk, exhibit higher baseline institutional readiness for circular waste initiatives and renewable energy development.

For example, in the Carpathian region, the number of private solar power plants increased by 40% per year. As of spring 2026, 217 industrial solar power plants with a total capacity of 354 MW were operating in the Ivano-Frankivsk region. For comparison, in February 2025, there were 156 such facilities (263 MW). Solar generation on the roofs of private houses is developing no less actively. Currently, 7289 home solar power plants with a total capacity of 178 MW are operating in the Carpathian region. The statistics include only plants operating under the "green tariff" mechanism. A year ago, there were 5290 such power plants, and their capacity was 137 MW (Savchyn, 2026).

Among the communities of the region, the highest indicators of industrial solar generation are demonstrated by the Ivano-Frankivsk, Tysmenyts'ka, Halyts'ka and Zabolotiv'ka communities. At the same time, the Snyatyn, Horodenkiv, Ivano-Frankivsk, Rohatyn and Kalus communities are leading in terms of the number of home solar power plants (Savchyn, 2026).

In the neighboring Lviv region, 144 renewable energy facilities with a total capacity of over 537 MW operate. In addition, over 4 thousand households have installed solar power plants. In 2026, it is planned to launch another 62 renewable energy generation facilities with a capacity of over 300 MW, which will strengthen the energy self-sufficiency of the region (Lviv regional administration, 2026).

A successful example of attracting foreign grant funds for the implementation of renewable energy projects in the Western macroregion is the United Nations Industrial Development Program (UNIDO), funded by the German Federal Ministry for Economic Cooperation and Development (BMZ), which helps Ukrainian municipalities stimulate recovery and reconstruction through green industrial solutions (UNIDO Knowledge Hub, 2026).

Last year project, implemented in three communities in the Lviv region, focused on inter-municipal cooperation to catalyze biogas production. It combined capacity building (training, study tours, etc.), local stakeholder engagement, comprehensive waste mapping, and feasibility studies for joint biogas plants. Its activities are aimed at increasing knowledge and technical readiness for green energy projects in line with Ukrainian norms and development plans. Drawing on international experience and focusing on cross-sectoral cooperation, the project strategy not only addresses urgent capacity gaps, but also lays the foundation for long-term, scalable, and replicable solutions.

An evaluation of the regional indicators and policy frameworks managed by the Ministry for Development of Communities and Territories of Ukraine demonstrates that a uniform national fiscal strategy for ecological taxation is structurally insufficient. The ongoing full-scale war has fundamentally disrupted the nation's socioeconomic geography, creating stark regional asymmetries in industrial capacity, environmental liabilities, and local revenue potential that a centralized, one-size-fits-all tax model cannot effectively address (UNECE, 2024).

Instead, ecological tax distribution must be structurally weighted. Directing a minimum of 60% of locally collected carbon and environmental taxes directly to municipal budgets within these specific affected regions will allow local communities to finance circular public procurement, process localized debris into secondary raw materials, and establish local Modernization Funds.

Key structural incongruities of an active state fiscal policy are: asymmetric destruction of industrial tax bases, demographic shifts and macro-regional enterprise relocation and divergence in local functional requirements.

The deliberate destruction of capital-intensive heavy industries (e.g., metallurgical and thermal power installations in eastern and southern oblasts like Dnipropetrovsk, Zaporizhzhia, and Kharkiv) has decimated traditional localized ecological and carbon tax revenue streams.

A uniform national strategy implicitly assumes a stable, homogenous baseline of emissions, which fails to account for the reality that frontier regions face severe environmental degradation but lack the active corporate tax base to generate localized recovery capital (UNIDO, 2026).

Data tracking internal migration indicates the displacement of millions of citizens alongside the physical relocation of hundreds of large-scale enterprises to safer western macro-regions (such as Lviv, Zakarpattia, and Ivano-Frankivsk). This geographic pivot has artificially intensified municipal pressure on western local communities. These hosting regions now experience an acute inflation in localized consumption emissions and municipal waste volumes, yet under a uniform system, they lack the legal and fiscal mechanisms to temporarily raise or retain ecological levies to fund defensive green infrastructure (Antoniuk et al., 2024).

The implementation of specialized diagnostic tools — including the Ministry's Geographic Information System (GIS) for regional monitoring — reveals that communities are highly fragmented by distinct functional needs. De-occupied and heavily shell-damaged northern and eastern zones require immediate, heavily subsidized fiscal interventions to process hundreds of thousands of tons of toxic military debris into secondary raw materials (UNECE, 2023). Conversely, western communities require proactive structural investments to integrate advanced circular waste management facilities and decentralized renewable energy grids (NEFCO, 2026).

6. Summary

In evaluating the critical research underpinning this policy synthesis, a notable limitation of the foundational model by Brown, Martinsson, and Thomann (2022) must be acknowledged. Their framework relies on historical, stable OECD datasets (1990-2012) and lacks the capacity to account for extreme macroeconomic shocks, localized institutional fragility, or the physical destruction of industrial assets characteristic of an active conflict zone. Furthermore, their focus on corporate absorptive capacity is centered heavily on high-knowledge-spillover manufacturing sectors, which may not directly translate to agrarian or severely disrupted regional municipal economies. Despite these weaknesses, the critical lesson learned and new knowledge highlighted by this synthesis is that environmental pricing operates more effectively as an organizational catalyst for technology adoption and absorption than as a driver for radical, proprietary invention.

The wider significance of this research lies in demonstrating how transitional and crisis-struck nations can strategically utilize environmental taxation not merely as a passive fiscal levy, but as a dynamic structural engine for localized green reconstruction. The practical information obtained from this analysis can be operationalized by Ukrainian legislators and international donors to draft municipal green procurement frameworks, calibrate regional

compliance pathways for the upcoming national ETS scheduled for 2028, and establish ring-fenced community funds. This structured financial model will empower local authorities to transform localized reconstruction liabilities into assets, accelerating the widespread integration of circular technologies across war-affected municipalities.

The centralized carbon and ecological pricing model in Ukraine must shift toward a geographically differentiated architecture. Rather than routing environmental revenues through centralized funding streams that distribute capital via rigid national formulas, the empirical and spatial data supports a structurally weighted policy:

- Local municipalities within de-occupied or high-impact functional zones should be legally empowered to retain a significantly higher proportion (e.g., 60% to 75%) of environmental tax receipts to finance immediate localized upcycling projects, bypassing rigid centralized limits.
- The national allocation of resources from the upcoming national Modernization Fund and Emissions Trading System (ETS) must be programmatically tied to the real-time damage layers and regional vulnerability metrics verified by the state's regional development databases.

Ultimately, replacing a rigid, uniform fiscal approach with an adaptive, region-specific ecological taxation framework is the only method to ensure that post-war recovery capital is directed exactly where environmental liabilities are highest.

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THE YIELD GAP AND THE NIIP – INVESTMENT INCOME NEXUS IN POLAND: A STRUCTURAL ANALYSIS

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Purpose: This paper assesses how the size and structure of external balance sheets affected Poland's investment income balance (IIB) dynamics between 2010 and 2025, evaluating whether Net International Investment Position (NIIP) consolidation yields proportional income flow corrections.

Design/Methodology/Approach: The research framework utilizes a linear regression model with a one-period lag to test the NIIP-to-investment income transmission. It also calculates annual implicit yields for external assets and liabilities to evaluate portfolio asymmetries and the international yield gap.

Findings: The results reveal a severe decoupling between external stock and flow positions, demonstrated by a weak, statistically insignificant relationship in the regression analysis. This lack of transmission is driven by a profound structural yield gap: low-yield official reserves suppress debt asset returns, whereas equity liabilities generate substantially higher costs. Furthermore, a persistent intra-category efficiency gap remains concentrated within the Foreign Direct Investment (FDI).

Practical Implications: Policies focused solely on nominal debt or NIIP reduction are insufficient. Policymakers must shift their focus toward enhancing the return efficiency of domestic assets abroad and upgrading Poland's position in global value chains to mitigate high-yield foreign capital outflows.

Originality/Value: While there is an intense academic debate about the privileges of the US external position, little research has explored the yield characteristics of foreign assets and liabilities in Poland. The study contributes to a better understanding of changing dynamics of Poland's investment income balance.

Keywords: Net International Investment Position; Investment income balance; Yield gap; Foreign Direct Investment; Poland.

Category of the paper: Research study.

JEL classification: F34, F4.

1. Introduction

Since the mid-1990s, the world economy has seen a rapid expansion of cross-border asset and liability holdings (Milesi-Ferretti, 2024; Lane, Milesi-Ferretti, 2018). Consequently, the dynamics of the investment income balance now play a crucial role in shaping the current account sustainability of small open economies (Adler, Garcia-Macia, 2018; Wacker, 2024). Empirical evidence by Behar and Hassan (2022) demonstrates that the income balance equals at least half of the trade balance for fifty percent of the countries in their sample.

In a standard theoretical framework, the relationship between external stock positions and investment income flows is straightforward: changes in the stock of external assets and liabilities mechanically impact investment income through a level effect (Knetsch, 2011). Consequently, a country with a higher net external liability position will tend to have a more negative net investment income, a more negative current account balance, and more net foreign borrowing needs, which in turn would decrease the income balance (Alberola et al., 2020).

However, the link between asset income flows and the international investment position is not as tight as one may expect (Donato, Tille, 2025). Some economies sustain large negative external positions without experiencing proportionally large income deficits, while others record deep and persistent imbalances despite relatively stable net asset positions (Gourinchas, Rey, 2007; Lane, Milesi-Ferretti, 2017).

These findings point to the importance of factors beyond the sheer size of external balance sheets. Specifically, they highlight how differences in the composition of countries' external assets and liabilities (Lane, Milesi-Ferretti, 2005, 2007) give rise to yield differentials, defined as the difference between the rate of return earned on external assets and the rate paid on external liabilities.

In this context, it is conceptually essential to distinguish between total returns and implicit yields. While total investment returns incorporate both current income and capital gains or losses driven by market asset prices and exchange rate fluctuations, implicit yields capture exclusively the current income streams—such as interest, distributed dividends, and reinvested earnings—relative to the capital stock (Curcuru et al., 2008). Since the primary income account of the balance of payments registers only these flows and excludes valuation effects, this paper focuses strictly on implicit yields. This focus ensures that the analysed yield gap reflects structural income servicing costs and receipts rather than transitory wealth variations.

While the existence of yield differentials is well-documented for major advanced economies, their dynamics in the context of Central and Eastern European (CEE) countries remain less explored. Poland, as a significant recipient of FDI with a concurrently large stock of official reserves, provides a compelling, yet understudied case for investigating how the interplay between the composition effect and the return effect shapes the long-term sustainability of the current account. To address this empirical gap, the main objective of this

paper is to assess how both the size and the structure of external balance sheets affected the investment income balance dynamics in Poland between 2010 and 2025. Specifically, this paper poses the following research question: to what extent can Poland's persistent net investment income payments be explained by the accumulation of the NIIP versus shifts in aggregate yields and portfolio composition?

The remainder of this paper is organized as follows: Section 2 reviews the relevant literature; Section 3 describes the data and decomposition methodology; Section 4 presents the empirical results; and Section 5 concludes.

2. An overview of the literature

The persistence of "income puzzles"—situations in which countries maintain a positive investment income balance despite negative external positions—has challenged the traditional view that investment income balances are mechanically determined by the net international investment position (Gourinchas, Rey, 2007; Gourinchas, Obstfeld, 2012; Gourinchas et al., 2019). These findings suggest that asymmetries in the rates of return on external assets and liabilities can substantially weaken, or even reverse, the expected relationship between the NIIP and the investment income balance.

The United States constitutes the most prominent example discussed in the literature, having maintained a positive investment income balance despite its persistent negative NIIP (Higgins et al., 2006). Gourinchas and Rey (2007) famously characterized the U.S. as the "world venture capitalist", arguing that its external balance sheet performs a form of international risk intermediation. According to this interpretation, the U.S. issues relatively safe and low-yield liabilities while holding riskier, higher-yield foreign assets, particularly FDI and portfolio equity (Forbes, 2010). Therefore, the IIP's composition is an important determinant of both the size and stability of investment income (Behar, 2025). For the U.S., the structure of external assets and liabilities ensures persistent excess returns on foreign assets, offsetting the negative income impact of a net liability position. Heath (2007) provides empirical support for the "world venture capitalist" thesis by demonstrating that the U.S. net income balance is driven by a persistent yield premium on foreign direct investment and low, stable yields on government debt.

Habib (2010) finds that, among major reserve – currencies issuers, Japan and Switzerland exhibit positive excess yields on foreign assets and liabilities comparable to those of the United States. By contrast, the euro area records, on average, negative excess yields, although its performance improved markedly during the 1990s and 2000s. However, once valuation effects and capital gains are taken into account, the United States remains the only major economy to

generate consistently positive and statistically significant excess total returns on its net foreign asset position.

While advanced economies may benefit from favourable return differentials on their external balance sheets, the opposite pattern is often observed in emerging market economies. The analyses by Lane and Milesi-Ferretti (2005, 2007) reveal a structural pattern that differs markedly to the U.S. "world venture capitalist" model. Emerging market economies (EME) typically exhibit a "short equity, long debt" portfolio composition. On the liability side, these economies rely heavily on high-yield FDI and portfolio equity, which closely links the returns paid to foreign investors to domestic economic performance. On the asset side, however, EME primarily accumulate low-yielding foreign exchange reserves and debt instruments (Alfaro et al., 2021; Matsumoto, 2022). This asymmetric asset–liability structure generates a persistent negative return differential for emerging markets. This structural drain on primary income illustrates how adverse yield differentials can amplify external vulnerabilities during periods of global financial stress (Cubeddu et al., 2023; Rey, 2013). Consistent with this argument, Joyce (2021) finds that the investment income deficit in emerging markets has widened as a result of the growing importance of FDI liabilities.

A more granular analysis focuses on yield differentials within specific investment categories. Research indicates that even within the same category of investment, returns on assets and liabilities are rarely symmetric. For instance, in the context of FDI, Curcuru, Thomas, and Warnock (2013) demonstrate a persistent and substantial yield premium on U.S. outward FDI relative to inward FDI, driven primarily by the higher profitability of U.S. foreign affiliates, rather than by capital gains. Calculations by Darvas and Hüttl (2017) confirm that the primary source of the U.S. yield advantage is the superior return on outward FDI assets relative to FDI liabilities. Colacelli et al. (2021) show that Japan's persistent current account surplus is largely sustained by an expanding primary income balance, fueled by high rates of return on outward FDI and a structurally low stock of FDI liabilities. These findings suggest that superior FDI returns are not unique to the U.S., as Japan's experience reflects a broader pattern of high-yielding foreign assets in certain advanced economies. By contrast, Darvas and Hüttl (2017) find that most European countries earn only average market returns on their foreign investments. However, Knetsch and Nagengast (2017) offer a more detailed perspective on income from Germany's foreign investment position, showing that Germany's foreign assets have generated significantly higher returns in recent years. According to their decomposition framework, this shift was driven particularly by favourable structural developments in outward equity FDI and long-term debt securities.

Habib (2010) examined differential returns on gross foreign assets and liabilities for a panel of 49 countries over the period 1981-2007 and found that excess investment income yields are positively associated with country risk ratings; that is, countries with better risk ratings tend to record more favourable investment income balances. Recent literature suggests that recorded yield gaps may also reflect non-economic factors. Zucman (2013) and Vicard (2023)

demonstrate that tax-motivated profit shifting by MNEs can artificially depress recorded yields on liabilities in high-tax jurisdictions while inflating them in tax havens. Such transfer pricing strategies can significantly distort the primary income account of the balance of payments, complicating the assessment of true economic returns. Bosworth et al. (2007) estimate that approximately one-third of the excess returns earned by U.S. foreign direct investment can be attributed to profit shifting arising from differences in national tax rates. Empirical evidence from EU member states confirms that aggressive tax planning and offshore financial center structures significantly distort investment income balances, creating a measurable divergence between tax-aggressive jurisdictions and the rest of the EU (Van Limbergen, 2020). As Lane and Milesi-Ferretti (2005) note, the massive expansion of gross positions means that even marginal shifts in these yield differentials can have a sizable impact on national income. This observation is consistent with Obstfeld (2012), who argues that in a world characterized by large gross external positions, valuation changes and return differentials can have macroeconomic effects comparable to those traditionally associated with trade imbalances.

Building on these insights, this paper evaluates whether Poland's persistent primary income deficit is driven primarily by the composition of its external balance sheet or by differences in asset-specific yields. The following section describes the methodology and data preparation.

3. Research methods

The empirical analysis is designed to examine the relationship between Poland's NIIP and the investment income balance, as well as to identify the structural drivers of the persistent income deficit. The study covers the period 2010–2025, utilizing annual data sourced from Eurostat.

To test the transmission efficiency between the stock of net external assets and the flow of investment income, a simple linear regression model was estimated. The model takes the following form:

$$IIB_{(t+1)} = \alpha + \beta(\Delta\, NIIP_t) + \varepsilon_t$$

where:

$IIB(t+1)$ is Investment Income Balance as percentage of GDP in period t+1,

$\Delta\, NIIPt$ represents the annual change in the NIIP as a percentage of GDP in period t,

β measures the reactivity of the investment income balance to changes in the NIIP,

εt denotes the error term.

The one-period lag was introduced to account for the time required for changes in the stock of assets and liabilities to manifest in realized income flows.

To identify the source of the yield gap, implicit annual yields were calculated. The implicit yield (i_t) for a given investment category in year t is defined as:

$$i_t = \frac{Income\ Flow_t}{Stock_{t-1}}$$

The yield is calculated as the ratio of the investment income flow (debit or credit) in year t to the stock of the corresponding assets or liabilities at the end of the preceding year t -1, which reflects the capital base available at the beginning of year t.

These implicit yields were calculated for total assets and liabilities, as well as for each functional category. Furthermore, external assets and liabilities were aggregated into two broader asset classes: equity instruments and debt instruments. Equity yields represent the weighted average of FDI and portfolio equity yields for assets and liabilities, respectively. Debt yields represent the weighted average of portfolio debt and other investment yields for liabilities, and the weighted average of portfolio debt, other investment, and official reserve asset yields for assets.

Finally, the yield differential (spread) was calculated to measure the efficiency gap between the return on assets and the cost of liabilities within each functional category:

$$Spread_t = i_{A,t} - i_{L,t}$$

where:

$i_{A,t}$ represents the implicit yield on assets in year t,

$i_{L,t}$ represents the implicit yield on liabilities in year t.

4. Results and discussion

Throughout the analyzed period, Poland maintained its status as a net debtor. In 2013, the negative NIIP peaked at 70% of GDP; since then, it has undergone significant consolidation, improving to -29.8% by the end of 2025. This substantial strengthening over the last decade is largely attributed to the deleveraging of the private sector and the dynamic accumulation of official reserve assets (NBP, 2024).

Consistent with its net debtor status, Poland has recorded a persistent net investment income deficit. This imbalance intensified between 2010 and 2016, peaking at 5% of GDP, before moderating to 3.7% in subsequent years. While the improvement in the NIIP is evident, the net investment income has recovered at a notably slower pace. The analysis reveals a weak positive correlation ($r = 0.31$), suggesting that the relationship between the country's net stock position and its flow of investment income is tenuous.

The results of the linear regression model estimation fully support the hypothesis regarding the lack of an effective transmission between the improvement of the NIIP and the investment income balance. The estimated coefficient for the explanatory variable was only *0.032*,

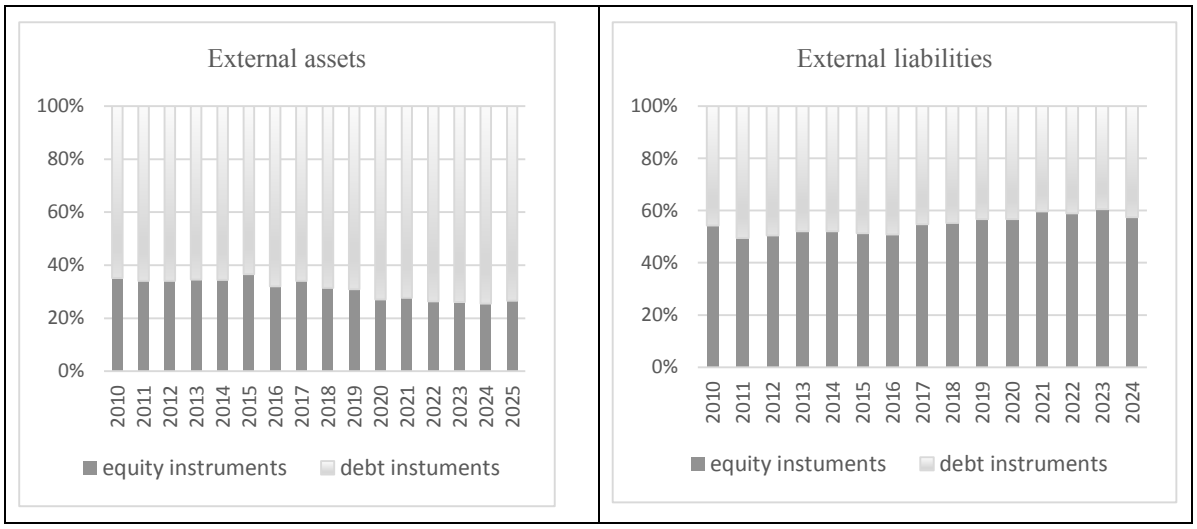
implying that a 1 percentage point improvement in NIIP (as % of GDP) results in a mere *0.03* percentage point increase in the investment income balance. Such low reactivity, combined with a lack of statistical significance (*p-value = 0.27*), suggests that the process of reducing Poland's negative net external position does not serve as an efficient tool for improving the current account balance in the income category. The structural nature of the income deficit is further evidenced by an estimated underlying deficit of *-4.4%* of GDP, which appears to remain unaffected by nominal changes in the stock of foreign assets and liabilities (Table 1).

Table 1.
Regression analysis results: Impact of ΔNIIP on Investment Income Balance (%GDP)

Variable / Statistic	**Value**
Coefficient	0.032
Constant	-4.425
R-squared	0.098
Correlation Coefficient	0.313
P-value	0.275
Number of observations	14

Source: own calculations based on Eurostat data: https://ec.europa.eu/eurostat/databrowser.

A comparative analysis of the external balance sheet structure reveals a profound asymmetry between assets and liabilities (Figure 1). While Poland's assets are heavily tilted toward debt instruments—accounting for approximately 70% of the total and largely dominated by official reserves which constitute around 40% of total assets—its liabilities exhibit a much higher concentration of equity instruments, fluctuating between 48% and 58% throughout the analyzed period, mainly in the form of FDI.



Note: Equity instruments equal to portfolio equity securities plus FDI; and debt instruments equals to portfolio debt securities plus other investments plus reserve assets.

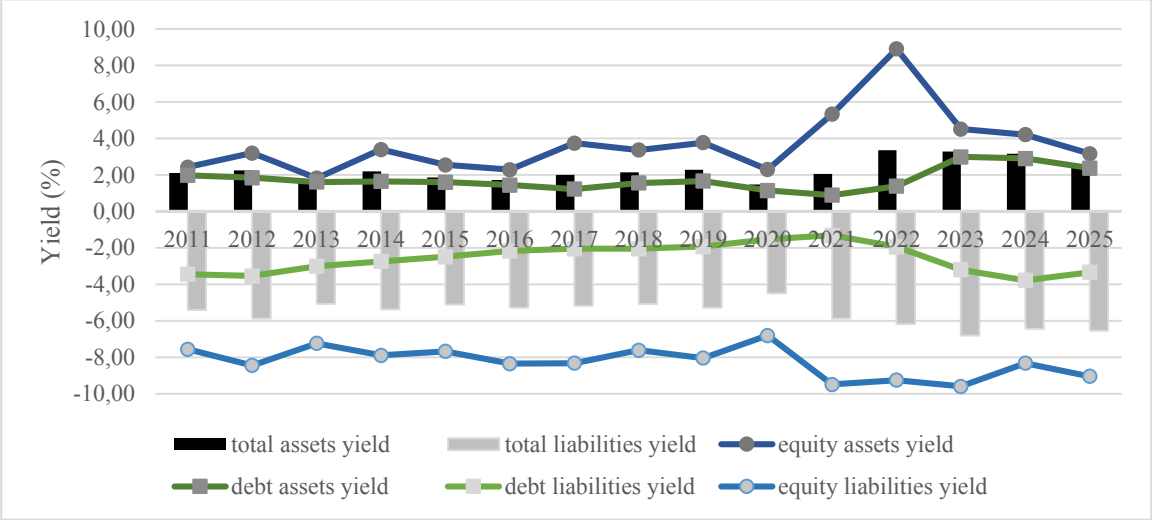
Figure 1. Structure of Poland's external assets and liabilities: equity vs. debt (%).

Source: own calculations based on Eurostat data: https://ec.europa.eu/eurostat/databrowser.

The comparison of implicit yields reveals a stark and persistent yield gap between Poland's external assets and liabilities (Figure 2). While the total return on assets remained subdued (averaging 1.5-2.5%), the total return on liabilities was significantly higher, consistently

exceeding 5.5%. This disparity is primarily driven by equity investments. Foreign equity capital invested in Poland yielded substantial returns, often surpassing 8%, standing in sharp contrast to the lower costs of servicing debt instruments (1.8-3.8%). On the asset side, equity investments were also more profitable than debt, although the spread between these two asset classes was surprisingly narrow, taking into consideration that a significant portion of debt instruments consists of official reserve assets that prioritize liquidity and security over high returns.

A detailed examination of intra-category yield differentials further illuminates this structural disadvantage (Figure 3). The "efficiency gap" is most pronounced in the FDI component, where the yield on liabilities exceeded that on assets by 4.2 to 6.9 percentage points (closing significantly only in 2022). This gap is largely attributable to investment maturity: foreign capital in Poland represents established, highly profitable projects, whereas Polish outward FDI is often in its nascent stages (NBP, 2025). Similarly, within other investments, yields paid to non-residents consistently exceed those earned by residents abroad throughout the 2011-2025 period, although this specific yield gap remained smaller. The underperformance was most severe in the later years, reaching its lowest point at -1.9 % before slightly moderating toward the end of the horizon.



Note: Yields on liabilities are presented with a negative sign for illustrative purposes to highlight the spread between investment returns and servicing costs.

Figure 2. Implicit yields on Poland's external assets and liabilities: equity vs. debt (%)

Source: own calculations based on Eurostat data: https://ec.europa.eu/eurostat/databrowser.

Yield differentials in both equity and debt portfolios reveal alternating periods in which either domestic or foreign investments were relatively more profitable. Negative gaps dominated the initial years and the final downturn in 2025, indicating periods when foreign investments outperformed Polish ones. Conversely, positive gaps in the middle of the horizon mark periods of higher profitability for Polish assets. While debt maintained more stable returns, the equity portfolio reached a higher peak of domestic profitability (1.69) but also suffered a significantly deeper underperformance abroad (-3.03 vs. -1.30 for debt).

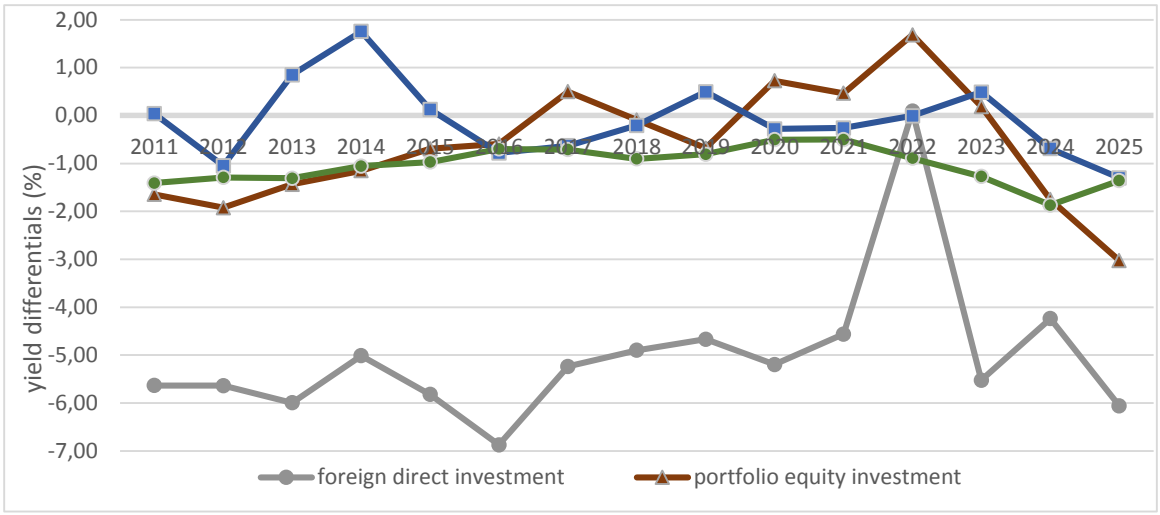


Figure 3. Asset–liability yield differentials by functional category (%).

Source: own calculations based on Eurostat data: https://ec.europa.eu/eurostat/databrowser.

The empirical findings presented above carry significant implications for understanding the structural features of Poland's external balance sheet and directly address the core research question. The observed lack of reactivity in the linear regression model confirms that Poland experiences a decoupling of external stocks and flows. This phenomenon aligns with the literature, which argues that investment income balances are not mechanically determined by net stock positions alone (Gourinchas, Rey, 2007; Habib, 2010; Lane, Milesi-Ferretti, 2007). In line with Behar (2025), these results confirm that a nominal reduction in external liabilities does not automatically translate into a proportional reduction in debt-servicing flows if underlying structural asymmetries are left unaddressed.

The primary driver of this decoupling is the structural asset-liability mismatch. Unlike major advanced international currency issuers such as the U.S., Japan, or Switzerland, which enjoy a positive yield privilege by issuing low-yield debt liabilities and holding high-yield foreign equity assets (Habib, 2010; Higgins et al., 2006), Poland exhibits the exact opposite portfolio composition. As conceptualized by Lane and Milesi-Ferretti (2007) for catching-up economies, Poland acts as a net equity debtor and a net debt creditor. This short equity, long debt portfolio composition locks a vast portion of domestic foreign assets into safe, low-yield instruments—such as official reserves that prioritize liquidity and security—while paying high risk and liquidity premiums on foreign liabilities (Joyce, 2021).

Beyond the composition effect, the discussion must account for the persistent intra-category efficiency gap, particularly within the FDI sector. Following the mechanisms identified by Gourinchas and Rey (2007) as well as Darvas and Hüttl (2017), the Polish data confirms that the return differential is heavily skewed against the domestic economy. While Curcuru et al. (2013) documented a persistent outward FDI yield premium for advanced economies due to highly competitive multinational firms, the sign of this efficiency gap is reversed in Poland. This reversal occurs because the domestic economy acts primarily as a host country for highly

efficient, mature foreign multinational enterprises, whereas Polish outward investments are often in their nascent, lower-yielding stages (NBP, 2025).

In summary, intra-category yield gaps, combined with the previously discussed composition effect, create a "double disadvantage" on the Poland's investment income balance, explaining why a nominal improvement in the NIIP fails to achieve a corresponding correction in net investment income flows. This confirms that the deficit is an inherent characteristic of Poland's position as a net importer of high-productivity capital (Gourinchas, Rey, 2007).

5. Conclusions

The empirical evidence presented in this study confirms that Poland's net investment income deficit is a deeply structural phenomenon. While the significant consolidation of the NIIP since 2013 has reduced the economy's external vulnerability, its impact on the primary income account has been largely neutralized by a persistent negative yield gap. This gap operates through two mutually reinforcing channels: the composition effect and the return effect.

On the one hand, the composition effect ensures that Poland's external liabilities are heavily dominated by expensive equity instruments, while its assets remain skewed toward low-yield liquid reserves. On the other hand, the return effect—most visible within the FDI sector—reveals that foreign capital operating in Poland achieves profitability levels that far exceed those of Polish investments abroad. This "double disadvantage" suggests that even a balanced international investment position might not sufficient to eliminate the income deficit, as the yield spread remains fundamentally stacked against domestic residents.

In conclusion, the primary income deficit is not merely the result of the economy's reliance on foreign capital, but is also a consequence of Poland's integration into the global financial system as a net importer of high-productivity capital and a provider of low-yield global liquidity. These findings have profound implications for Poland's long-term current account sustainability, suggesting that future policy measures must shift their focus from nominal debt reduction toward enhancing the return efficiency of domestic assets abroad and upgrading the country's position in global value chains. An important direction for future research would be to examine the factors underlying the persistently higher returns on Poland's FDI liabilities relative to its outward FDI assets.

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AUTONOMOUS VEHICLES IN URBAN LAST-MILE DELIVERY. A DELPHI-BASED ASSESSMENT OF ADOPTION PROSPECTS

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Purpose: This paper aims to assess the adoption prospects of autonomous vehicles in urban last-mile courier delivery.
Design/methodology/approach: A qualitative Delphi study was conducted. The Delphi research form included four future-oriented theses concerning the use of autonomous vehicles by courier companies. The factors supporting and hindering the implementation of the theses were identified on the basis of the literature review. The paper presents findings from the Delphi study. Expert assessments were synthesised using significance, favourability and barrier indicators derived from research.
Findings: The results indicate that experts perceive autonomous vehicles as a plausible future component of courier fleets, rather than a short-term replacement for all other last-mile delivery solutions. Experts assigned the strongest support to the development of autonomous vehicle technology, the possibility of co-financing purchases and the readiness of urban infrastructure. The main barriers were the cost of purchasing autonomous vehicles, legal uncertainty, limited service facilities, difficulties in obtaining spare parts and concerns about the safety of technological solutions.
Research limitations/implications: The study is based on a limited expert panel and presents exploratory findings. Future research should involve a larger and more diverse group of experts and allow comparison between stakeholder groups.
Practical implications: The findings can support courier companies, city authorities and policymakers in planning conditions for testing and implementing autonomous vehicles in urban logistics.
Social implications: The study points to the need to consider public acceptance, safety and environmental expectations when introducing autonomous delivery solutions in cities.
Originality/value: The paper contributes an expert-based Delphi assessment of autonomous vehicles in urban last-mile delivery and identifies factors that may shape their adoption.
Keywords: autonomous vehicles; last-mile delivery; urban logistics; Delphi method.
Category of the paper: Research paper.

1. Introduction

E-commerce has changed the organisation of retail distribution. It has increased the number of small, frequent and geographically dispersed deliveries to individual customers. This change has shifted part of retail competition from store accessibility and product availability to the quality of order fulfilment and delivery performance. In online retailing, physical distribution service quality includes such dimensions as delivery reliability, timeliness, product availability, information quality and returns handling. Therefore, in last-mile logistics, service quality is often assessed at the point where the parcel reaches the recipient. This makes the final delivery stage a source of market differentiation and customer value creation. At the same time, it creates operational pressure for retailers, logistics service providers and courier companies (Xing et al., 2010; Lim et al., 2018; Mangiaracina et al., 2019; Raźniewska et al., 2026).

Customers expect short delivery times, reliable information, flexible delivery options, convenient returns and, increasingly, low or no delivery charges. The popularity of next-day delivery and free delivery models increases the tension between customer convenience, operational efficiency and environmental sustainability. These expectations reduce the possibilities for shipment consolidation. They also increase the number of delivery trips in urban areas, particularly when home delivery is used as the dominant fulfilment model. As a result, the last mile has become one of the most demanding parts of the supply chain. It is costly, service-sensitive, difficult to standardise and strongly dependent on local demand density, urban form and customer behaviour (Visser et al., 2014; Allen et al., 2018; Buldeo Rai et al., 2019; Boysen et al., 2021; Olsson et al., 2019).

The pressure is particularly visible in cities. Urban areas concentrate demand for parcel delivery, but they also concentrate congestion, limited road space, curbside competition, noise and emissions. Freight transport is necessary for urban economic activity, but it also generates negative externalities that must be managed through transport policy, land-use planning and cooperation between public and private stakeholders. City logistics must therefore combine economic efficiency with quality of life and environmental objectives. This makes urban last-mile delivery not only a logistics problem, but also a matter of transport policy, spatial planning, environmental management and public acceptance (Dablanc et al., 2013; Savelsbergh, van Woensel, 2016; Viu-Roig, Alvarez-Palau, 2020; Kiba-Janiak et al., 2021; Wolniak, 2023).

The literature proposes different ways of improving last-mile delivery. These include parcel lockers, pickup and drop-off points, cargo bikes, electric vans, crowdsourcing, drones and autonomous delivery systems. Parcel lockers and other out-of-home delivery solutions are often discussed as ways to reduce failed deliveries, improve consolidation and limit the environmental burden of individual home deliveries. Green last-mile solutions are also increasingly analysed in relation to customer preferences and the willingness of e-commerce users to choose more sustainable delivery options when information about environmental

impacts is available. These solutions differ in terms of technological maturity, cost structure, infrastructure needs, environmental performance and social acceptance. They should not be treated as mutually exclusive. In many cities, future last-mile delivery will probably be based on a combination of several solutions adapted to local conditions (Iwan et al., 2016; Ranieri et al., 2018; Ignat, Chankov, 2020; Mucowska, 2021; Lauenstein, Schank, 2022).

Autonomous vehicles are one of the most discussed directions of change in urban delivery. In this paper, the term refers to ground-based driverless delivery solutions used in courier operations, including autonomous delivery vehicles and smaller autonomous delivery robots. Their potential is linked to lower dependence on human drivers, more flexible delivery models and better use of local distribution systems. Previous studies indicate that such solutions may reduce delivery time and operational costs in selected contexts. They may also limit some external effects of urban freight transport, especially when autonomous delivery is integrated with electric propulsion, local hubs or other low-emission delivery systems (Baum et al., 2019; Figliozzi, 2020; Chen et al., 2021; Engesser et al., 2023; Jennings, Figliozzi, 2019; Guzowski, Szpilko, 2025).

However, the implementation of autonomous vehicles in courier services remains uncertain. It depends on technological development, urban infrastructure, legal regulations, safety, public acceptance and investment capacity. In addition, autonomous delivery requires an operational ecosystem that includes charging facilities, remote supervision, maintenance services, data management, liability rules and procedures for interaction with pedestrians, cyclists and other road users. The literature also points to the limited number of real-world implementations and the early stage of empirical research on autonomous delivery systems. For this reason, adoption prospects should be assessed not only from a technical perspective, but also from an organisational, economic, legal, environmental and social perspective (Hoffmann, Prause, 2018; Kapser, Abdelrahman, 2020; Alverhed et al., 2024; Yuen et al., 2022; Koh et al., 2024).

Existing research discusses many operational and technological aspects of autonomous delivery, including routing, fleet configuration, customer acceptance, safety, environmental performance and regulatory conditions. At the same time, last-mile logistics research remains fragmented across several disciplines, including transport studies, logistics, operations research, sustainability research, consumer behaviour and urban policy. Less attention has been paid to expert assessments of how and under what conditions autonomous vehicles may become part of courier fleets in urban last-mile delivery. This research gap is important because decisions concerning autonomous delivery are made under uncertainty. The technology is developing, but its wider use depends on several interrelated factors that cannot be assessed only on the basis of current empirical data (Olsson et al., 2019; Engesser et al., 2023; Alverhed et al., 2024).

In such conditions, the Delphi method is useful as a qualitative expert method that supports the structured assessment of future developments when precise empirical data are limited. The method enables the collection and refinement of expert judgements through iterative rounds, controlled feedback and systematic analysis of opinions. It is therefore suitable for

studying emerging technologies and complex socio-technical systems, especially when future adoption depends on technological, market, regulatory and social factors. In this study, the Delphi method was used to assess supporting factors and barriers to the adoption of autonomous vehicles in urban last-mile delivery (Rowe, Wright, 1999; Landeta, 2006; Belton et al., 2019; Beiderbeck et al., 2021).

The purpose of this paper is to assess the adoption prospects of autonomous vehicles in urban last-mile courier delivery. The study focuses on the significance, probability and expected time horizon of selected future-oriented theses concerning autonomous vehicles in courier services. It also examines factors supporting and hindering their implementation. These factors were identified on the basis of the literature review and then assessed by experts in a Delphi study.

The study addresses the following research questions:

RQ1: How do experts assess the significance, probability and expected time horizon of future theses concerning the use of autonomous vehicles in urban last-mile courier delivery?

RQ2: Which factors are perceived as supporting the implementation of autonomous vehicles in courier companies' last-mile delivery operations?

RQ3: Which barriers are perceived as limiting the implementation of autonomous vehicles in urban courier delivery?

The remainder of the paper is organised as follows. Section 2 presents the literature review and identifies factors supporting and hindering the adoption of autonomous vehicles in urban last-mile delivery. Section 3 describes the research methodology, with particular attention to the qualitative Delphi study. Section 4 presents the results from the Delphi study. Section 5 discusses the findings in relation to courier companies, city logistics and urban transport policy. The final section presents conclusions, limitations and directions for future research.

2. Literature review

E-commerce has changed the structure of urban freight flows. It has increased the number of small parcels delivered to dispersed recipients. It has also strengthened customer expectations concerning speed, flexibility and delivery visibility. As a result, last-mile delivery has become one of the most complex stages of the supply chain. It combines operational efficiency, customer service and urban transport constraints (Lim et al., 2018; Mangiaracina et al., 2019).

The last mile is especially difficult in cities. Urban areas concentrate demand for courier services, but they also suffer from congestion, limited curb space, noise and emissions. These effects are not only private costs borne by logistics operators. They are also external costs

borne by residents, local authorities and other road users (Ranieri et al., 2018; Viu-Roig, Alvarez-Palau, 2020). For this reason, last-mile delivery should be considered as part of city logistics. City logistics aims to improve freight distribution while reducing the negative effects of transport in urban areas (Savelsbergh, van Woensel, 2016).

The literature identifies several solutions that may improve the last-mile delivery process. These include parcel lockers, pickup and drop-off points, cargo bikes, electric vans, crowdsourcing, drones and autonomous delivery systems. These solutions differ in terms of cost, infrastructure needs, environmental effects and customer acceptance. They should not be treated as direct substitutes in every urban context. In many cases, the future of last-mile delivery will probably be based on a combination of several solutions adapted to city structure, delivery density and service requirements (Boysen et al., 2021; Ranieri et al., 2018).

Autonomous delivery solutions are one of the most discussed directions of change. They include autonomous delivery robots, road autonomous delivery vehicles and multi-tier systems combining conventional vehicles with smaller autonomous units. In this paper, the term autonomous vehicles refers to ground-based driverless delivery solutions used or potentially used in courier operations. Drones are treated only as a contextual example of autonomous delivery technology.

Autonomous vehicles may support last-mile delivery in several ways. They may reduce dependence on human drivers, improve fleet availability, enable contactless delivery and support more flexible routing. Studies on sidewalk autonomous delivery robots indicate that they may reduce delivery time and travel per package in selected operating conditions (Jennings, Figliozzi, 2019). Other studies show that truck-and-robot systems can improve delivery efficiency when routes, delivery density and robot availability are properly coordinated (Boysen et al., 2018; Ostermeier et al., 2022). However, these benefits are not automatic. They depend on the maturity of the technology, urban infrastructure and the ability to integrate autonomous vehicles into existing logistics networks.

The literature also shows that autonomous delivery systems remain at an early stage of implementation. Engesser et al. (2023) indicate that autonomous delivery solutions require further research on energy demand, legislation, safety, implementation strategy and cooperation between stakeholders. Alverhed et al. (2024) show that autonomous delivery robots may reduce costs, improve time use and reduce some externalities. At the same time, they point to infrastructure, regulation and social acceptance as key challenges.

These findings are important for courier companies. The courier sector competes through delivery speed, reliability, cost efficiency and service flexibility. Autonomous vehicles may therefore become a source of competitive advantage if they reduce operating costs or enable new delivery models. This leads to the first future-oriented Delphi thesis: Increased use of autonomous vehicles will result in increased competition among courier companies (T1).

The environmental dimension is also important. The European Green Deal and the Sustainable and Smart Mobility Strategy indicate the need to reduce greenhouse gas emissions from transport and move toward low-emission and zero-emission mobility (European Commission, 2019, 2020). EU regulations on CO_2 emission standards for new cars and vans also increase pressure on the road transport sector to decarbonise vehicle fleets (European Parliament and Council, 2023). In last-mile delivery, this supports the development of electric vans, cargo bikes and other low-emission solutions. Autonomous vehicles may be part of this transition if they are based on electric propulsion and if their life-cycle effects are favourable.

However, the literature does not indicate that autonomous vehicles are the only sustainable solution for last-mile delivery. Life-cycle studies show that environmental effects depend on the vehicle type, delivery system design, electricity mix, load factor and production impact (Figliozzi, 2020; Lemardelé et al., 2023; Temporelli et al., 2022). Therefore, the second thesis should be treated as a strong future scenario submitted to expert assessment, rather than as an established fact from the literature: Autonomous vehicles will become the only way to deliver courier shipments consistent with Green Deal policies (T2).

Urban policies may also influence the adoption of autonomous delivery. Cities may introduce low-emission zones, access restrictions, curbside management rules and safety requirements for vehicles operating in dense urban space. For autonomous delivery robots, regulations are particularly important because these vehicles may operate on sidewalks, shared spaces or local roads. Hoffmann and Prause (2018) show that autonomous delivery robots create legal questions concerning traffic rules, liability and compliance. Alverhed et al. (2024) also point out that the lack of clear regulation creates uncertainty for market actors. This supports the third future-oriented thesis: City regulations and transportation policies in large metropolitan areas will eliminate the remaining delivery options other than autonomous vehicles (T3).

At the same time, the most moderate scenario is that autonomous vehicles will not replace all other delivery solutions but will become one component of courier fleets. Such a scenario is consistent with the literature on hybrid last-mile systems. Autonomous vehicles can operate together with conventional vehicles, electric vans, cargo bikes, parcel lockers and pickup points. Their role may be limited to selected areas, delivery types or time windows. This leads to the fourth Delphi thesis: Autonomous vehicles will be part of courier companies' fleets (T4).

The scale and pace of autonomous vehicle adoption will depend on several conditions. On the basis of the literature review, ten supporting factors were identified. These factors were used to prepare the Delphi research form.

For the purposes of this study, supporting factors are understood as conditions that may facilitate the implementation, diffusion and long-term use of autonomous vehicles in urban last-mile delivery (Table 1). They refer both to external conditions, such as public policy, legal regulations, infrastructure readiness and environmental requirements, and to internal technological and market-related conditions, including technology maturity, safety, consumer

acceptance and energy efficiency. The identified factors therefore reflect the multidimensional nature of autonomous vehicle adoption, which depends not only on the availability of the technology itself, but also on the institutional, social, environmental and operational context in which it is introduced.

Table 1.
Supporting factors for the adoption of autonomous vehicles in urban last-mile delivery

Code	Supporting factor	Literature basis
S1	Possibility of co-financing the purchase	High initial investment costs may limit adoption. Public support can reduce entry barriers for companies introducing low-emission and autonomous delivery technologies (European Commission, 2020).
S2	Readiness of urban infrastructure	Autonomous delivery requires adapted urban infrastructure, safe operating space, charging facilities and integration with local transport systems (Alverhed et al., 2024; Engesser et al., 2023; Hoffmann, Prause, 2018).
S3	Development of autonomous vehicle technology	Technology maturity is a basic condition for reliable operation. This includes sensors, navigation, remote supervision, communication systems and route optimisation (Baum et al., 2019; Engesser et al., 2023; Jennings, Figliozzi, 2019).
S4	Level of acceptance of autonomous vehicles	Consumer acceptance depends on perceived usefulness, perceived risk, trust and social influence. These factors are crucial for autonomous delivery services (Kapser, Abdelrahman, 2020; Koh et al., 2024; Yuen et al., 2022).
S5	Ensuring safety	Safety concerns relate to pedestrians, traffic interactions, theft, cyber risks and service reliability. Safety is therefore a condition for public acceptance and regulatory approval (Koh et al., 2024; Hoffmann, Prause, 2018; Jennings, Figliozzi, 2019; Kapser, Abdelrahman, 2020).
S6	Legal and regulatory framework	Clear regulations can reduce uncertainty for courier companies and technology providers. They concern vehicle approval, liability, traffic rules and operating zones (Alverhed et al., 2024; Hoffmann, Prause, 2018).
S7	Compliance with the requirements of the Green Deal	EU climate and mobility policies support the shift toward low-emission transport. Autonomous vehicles may contribute to these goals if they are integrated into low-emission delivery systems (European Commission, 2019, 2020; European Parliament and Council, 2023).
S8	Ecological awareness and consumer pressure	Environmental expectations may influence companies' delivery strategies and customers' acceptance of greener solutions (Ranieri et al., 2018; Viu-Roig, Alvarez-Palau, 2020).
S9	Ecological safety related to the construction of an autonomous vehicle	The environmental value of autonomous vehicles depends not only on operation, but also on production, batteries, materials and end-of-life processes (Lemardelé et al., 2023; Temporelli et al., 2022).
S10	Progress in research and production of power systems for autonomous vehicles	Electric propulsion, battery range, charging systems and energy efficiency influence the feasibility of autonomous last-mile delivery (Figliozzi, 2020; Lemardelé et al., 2023; Temporelli et al., 2022).

Source: Authors' own elaboration based on the literature review.

In addition to factors that may support implementation, the literature also points to a set of barriers that can slow down or limit the adoption of autonomous vehicles in urban last-mile delivery (Table 2). These barriers concern economic, regulatory, technological, organisational and infrastructural constraints. They are particularly important because autonomous delivery systems are still at an early stage of market development, and their implementation requires not only investment in vehicles, but also the creation of a broader operational ecosystem, including maintenance facilities, legal frameworks, safety procedures and user acceptance. The barriers

identified in the literature were therefore included in the Delphi form as potential obstacles to the practical deployment of autonomous vehicles in courier and urban delivery services.

Table 2.
Barriers to the adoption of autonomous vehicles in urban last-mile delivery

Code	Barrier	Literature basis
B1	Costs of purchasing an autonomous vehicle	High capital expenditure may reduce the willingness of courier companies to introduce autonomous fleets, especially when the business model is still uncertain (Sindi, Woodman, 2020; Alverhed et al., 2024; Engesser et al., 2023).
B2	Autonomous vehicle parts disposal costs	Battery systems, electronic components and vehicle materials may create environmental and cost challenges at the end of the life cycle (Lemardelé et al., 2023; Temporelli et al., 2022).
B3	Costs of operating an autonomous vehicle	Operating costs include energy, maintenance, software, supervision, insurance and fleet management. They determine whether autonomous delivery is competitive with conventional delivery (Jennings, Figliozzi, 2019; Ostermeier et al., 2022; Sindi, Woodman, 2020).
B4	Legal barriers	Unclear rules on road or sidewalk access, liability and vehicle approval may slow down implementation (Alverhed et al., 2024; Hoffmann, Prause, 2018).
B5	Insufficient safety and security of technological solutions	Perceived risk, safety concerns and lack of trust may limit acceptance among consumers, pedestrians and public authorities (Kapser, Abdelrahman, 2020; Yuen et al., 2022).
B6	Lack of openness to innovation	New delivery technologies require acceptance by companies, consumers and local stakeholders. Resistance may arise when benefits are unclear or perceived risks are high (Kapser, Abdelrahman, 2020; Koh et al., 2024).
B7	Lack of specialised service points	Autonomous vehicle adoption requires a service ecosystem for repairs, diagnostics, software support and maintenance. This is linked to technology maturity and operational readiness (Alverhed et al., 2024; Engesser et al., 2023).
B8	Difficulty in getting spare parts	Limited availability of components may increase downtime and operational risk, especially at the early stage of market development (Sindi, Woodman, 2020).

Source: Authors' own elaboration based on the literature review.

The reviewed literature shows that autonomous vehicles may become an important element of urban last-mile delivery. Their adoption is not determined only by technical progress. It also depends on public policy, infrastructure, financial support, safety, social acceptance and environmental performance. These conditions justify the use of the Delphi method. Expert assessment is useful because autonomous delivery remains an emerging area, and many implementation conditions are still uncertain.

3. Methods

This study was designed as a qualitative Delphi study. The Delphi method was selected because the adoption of autonomous vehicles in urban last-mile courier delivery is still an emerging issue. In such areas, empirical data are limited, and expert judgement is important for assessing possible future developments. The method is useful when the research problem

requires structured expert assessment rather than statistical generalisation (Linstone, Turoff, 1975; Rowe, Wright, 1999; Okoli, Pawlowski, 2004; Landeta, 2006; Ejdys et al., 2023; Szpilko et al., 2025).

The study has an expert-based and qualitative character. The numerical indicators used in the paper serve only to organise and synthesise expert opinions. They are not treated as inferential statistics. The results should therefore be understood as a structured expert assessment of adoption prospects, supporting factors and barriers.

The research process consisted of five stages, following the logic used in Delphi-based studies of emerging technologies (Ejdys et al., 2025).

Table 3.
Stages of the Delphi research process

No.	Stage	Description
1.	Literature review	The literature review was used to formulate Delphi theses and identify factors supporting and hindering the adoption of autonomous vehicles in urban last-mile delivery.
2.	Preparation of the Delphi research form	A structured research form was prepared. It included four future-oriented theses, questions related to each thesis, and supporting factors and barriers.
3.	Expert selection and data collection	Experts were selected purposefully and recruited using snowball sampling. The research form was distributed to experts representing courier companies, business practice, academia and couriers.
4.	Expert assessment	Experts assessed the significance, probability, expected time horizon, supporting factors and barriers related to the four theses.
5.	Final analysis and reporting	Expert assessments were synthesised using significance, favourability and barrier indicators. The results were then interpreted in relation to the research questions.

Source: Authors' own elaboration.

The Delphi research form included four theses concerning the possible role of autonomous vehicles in courier companies' urban last-mile delivery operations:

T1: Increased use of autonomous vehicles will result in increased competition among courier companies.

T2: Autonomous vehicles will become the only way to deliver courier shipments consistent with Green Deal policies.

T3: City regulations and transportation policies in large metropolitan areas will eliminate the remaining delivery options other than autonomous vehicles.

T4: Autonomous vehicles will be part of courier companies' fleets.

For each thesis, the same set of research questions was used. Experts were asked to assess:

1. the significance of the thesis for the development of the courier market,
2. the expected time horizon and probability of the thesis being realised,
3. the extent to which selected factors support the implementation of the thesis,
4. the extent to which selected barriers hinder the implementation of the thesis.

The supporting factors and barriers were identified on the basis of the literature review. The Delphi research form included ten supporting factors: possibility of co-financing the purchase, readiness of urban infrastructure, development of autonomous vehicle technology,

level of acceptance of autonomous vehicles, ensuring safety, legal and regulatory framework, compliance with the requirements of the Green Deal, ecological awareness and consumer pressure, ecological safety related to the construction of an autonomous vehicle, and progress in research and production of power systems for autonomous vehicles. The form also included eight barriers: costs of purchasing an autonomous vehicle, autonomous vehicle parts disposal costs, costs of operating an autonomous vehicle, legal barriers, insufficient safety and security of technological solutions, lack of openness to innovation, lack of specialised service points, and difficulty in getting spare parts.

The selection of experts was purposeful. Expertise was understood as academic knowledge or practical experience related to courier services, last-mile delivery, urban logistics, transport technologies, business processes or the use of delivery services. The Delphi study was conducted in March and April 2025. The panel consisted of 6 representatives of courier companies (30%), 4 active couriers (20%), 5 academic researchers specialising in logistics and transport (25%), and 5 representatives of the broader logistics and business environment (25%). Five participants were aged 18-25. Age was not a selection criterion, and each of these participants was included on the basis of documented professional, operational or research experience relevant to last-mile delivery. Experts were recruited using the snowball sampling method. The recruitment covered Polish companies and Polish branches of international companies operating in courier services, logistics, e-commerce, transport, last-mile delivery and technology-related business services. The business experts had at least five years of professional experience in managerial, specialist or operational positions related to courier services, logistics, transport, urban delivery or business process management. Academic experts were selected on the basis of their research experience in logistics, management, transport or new technologies. The Delphi panel included representatives of courier companies, the wider business environment, academics and couriers. This composition made it possible to include both theoretical and practical perspectives on the implementation of autonomous vehicles. It also enabled the assessment of the analysed theses from strategic, operational and user-oriented perspectives.

The paper reports the results from the Delphi study. The research included 20 completed Delphi forms. The structure of the expert panel is presented in Table 4.

Table 4.
Characteristics of the Delphi panel

Category	Structure of the expert panel
Gender	Female – 55%; Male – 45%
Age	18-25 years – 25%; 26-35 years – 30%; 36-45 years – 25%; 46-55 years – 20%
Education	Secondary education – 20%; Bachelor's or engineering degree – 25%; Master's degree – 55%
Professional activity	Representatives of courier companies – 30%; Active couriers – 20%; Academic researchers specialising in logistics and transport – 25%; Representatives of the broader logistics and business environment – 25%

Source: Authors' own elaboration.

The assessment of the significance of each thesis was synthesised using the significance indicator WI. The indicator was adopted from foresight research using the Delphi method (Ejdys, 2013). It was calculated as follows:

$$WI = \frac{n_{VS} \cdot 100 + n_S \cdot 75 + n_{RS} \cdot 25 + n_{NS} \cdot 0}{n - n_{NO}} \quad (1)$$

where:
n_{VS} – number of "very significant" answers,
n_S – number of "significant" answers,
n_{RS} – number of "rather significant" answers,
n_{NS} – number of "not significant" answers,
n_{NO} – number of "no opinion" answers,
n – total number of answers.

The indicator takes values from 0 to 100. A higher value means that experts assigned greater significance to a given thesis.

The strength of supporting factors was calculated using the favourability indicator WF. The indicator was also based on the approach used in foresight Delphi research (Ejdys, 2013):

$$WF = \frac{n_{VGE} \cdot 100 + n_{GE} \cdot 75 + n_{ME} \cdot 50 + n_{LE} \cdot 25 + n_{VLE} \cdot 0}{n - n_{NO} - n_{NR}} \quad (2)$$

where:
n_{VGE} – number of "to a very great extent" answers,
n_{GE} – number of "to a great extent" answers,
n_{ME} – number of "to a medium extent" answers,
n_{LE} – number of "to a low extent" answers,
n_{VLE} – number of "to a very low extent" answers,
n_{NO} – number of "no opinion" answers,
n_{NR} – number of "factor is not related to the thesis" answers,
n – total number of answers.

The same logic was used to calculate the barrier indicator WB. In this case, the indicator measured the strength with which a given barrier hindered the implementation of a thesis. Values closer to 100 indicate a stronger barrier.

For the expected time horizon of implementation, experts selected one of the following periods: by the end of 2025, between 2025 and 2035, after 2035, or never. The probability of implementation was assessed in five ranges: 0-20%, 21-40%, 41-60%, 61-80%, and 81-100%.

The final analysis was based on the Delphi results. The findings were interpreted in relation to the research questions concerning the significance and probability of the theses, supporting factors and barriers to the implementation of autonomous vehicles in urban last-mile courier delivery.

4. Results

4.1. Significance of the theses

The expert assessment of the four future-oriented theses reveals a cautious approach to the adoption of autonomous vehicles in urban last-mile courier delivery. The highest significance was assigned to the thesis that autonomous vehicles will become part of courier companies' fleets. More radical theses, especially those assuming the full replacement of other delivery options, were assessed with greater restraint. The values of the significance indicator are presented in Table 5.

Table 5.
Significance indicators for the Delphi theses

Thesis	Thesis statement	Significance indicator
T1	Increased use of autonomous vehicles will result in increased competition among courier companies.	37.50
T2	Autonomous vehicles will become the only way to deliver courier shipments consistent with Green Deal policies.	28.75
T3	City regulations and transportation policies in large metropolitan areas will eliminate the remaining delivery options other than autonomous vehicles.	55.00
T4	Autonomous vehicles will be part of courier companies' fleets.	68.80

Source: Authors' own study based on the Delphi study.

The highest value was obtained for Thesis 4, which assumes that autonomous vehicles will become part of courier companies' fleets (68.80). This result indicates that experts considered fleet integration the most relevant scenario. The qualitative justifications show that this thesis was associated with operational efficiency, cost reduction and adaptation to future regulatory requirements. One expert stated that autonomous vehicles may "increase operational efficiency, reduce costs and allow companies to better adapt to new regulations and social expectations". Another expert indicated that the introduction of such vehicles would not be limited to transport processes, because "if autonomous vehicles become part of the fleet, this will affect the functioning of the whole company, its structure and employment".

At the same time, the experts' comments show that this scenario was not perceived as simple or unconditional. Some respondents referred to the practical tasks that still require human involvement. One expert asked: "Who will load it into the car?". Another noted that couriers deliver "100-120 parcels a day" and argued that, under current conditions, they may remain more effective than autonomous vehicles. A similar concern was expressed in the comment that autonomous vehicles may influence "jobs and social trust in individual companies". These statements explain why Thesis 4 received the highest assessment but should still be interpreted as a scenario of gradual fleet diversification rather than immediate automation of courier work.

Thesis 3 received the second highest significance indicator (55.00). Experts recognised the role of city regulations and transport policies in shaping delivery systems. Their comments suggest, however, that they did not expect a fast elimination of traditional delivery options. One expert wrote that "complete elimination of traditional forms of delivery is unlikely in the short term", although urban policies such as low-emission zones or access restrictions may force courier companies to change their fleets. Another respondent stressed that "regulations may significantly limit many activities, especially in the case of small and medium-sized companies". This points to the regulatory importance of the thesis, but also to its potential economic and organisational consequences.

The qualitative material also shows that experts were sceptical about the idea of creating a single dominant delivery technology. One respondent stated that "zero-emission vehicles, electric vehicles and cargo bikes already meet the requirements of large agglomerations" and added that "a monopoly of autonomous vehicles should not be created". This comment is important because it shows that experts did not reject regulatory pressure, but they questioned the exclusiveness of autonomous vehicles as the only future urban delivery mode.

Thesis 1 received a lower significance indicator (37.50). The comments reveal two opposite interpretations of the relationship between autonomous vehicles and competition. Some experts perceived autonomous vehicles as a possible source of competitive advantage. One respondent stated that "the use of autonomous vehicles may significantly reduce operating costs, shorten delivery times and increase efficiency, which will create a competitive advantage". Another expert indicated that courier companies "will try to use autonomous vehicles in the best possible way in order to gain stronger market support".

However, the sceptical comments were more frequent and more operationally grounded. One expert wrote: "The vehicle will only be able to drive to the address by itself. The rest will still have to be done by the courier". Another respondent referred to everyday delivery problems: "In most areas, people are not at home and ask for the parcel to be hidden. An autonomous vehicle will not do this for you". A further comment stressed that "errors in address markings are very large" and that couriers often recognise an address only because a customer orders frequently. These opinions show that experts saw important limits to the competitive potential of autonomous vehicles. They did not perceive driving automation as equivalent to full automation of the courier service.

The lowest significance was assigned to Thesis 2 (28.75). This thesis assumed that autonomous vehicles would become the only delivery solution consistent with Green Deal policies. Experts' comments suggest that the low assessment resulted mainly from the exclusive wording of the thesis. One respondent wrote that "there are also alternatives, such as cargo bikes, electric vans or public transport, which also meet the objectives of the Green Deal". Another expert stated that "an electric car with a driver is equally harmless to the environment". These opinions indicate that experts perceived environmental transformation in last-mile delivery as a broader process that may include several low-emission solutions.

Some comments also reflected doubts about the financial feasibility of Green Deal-oriented transformation in courier services. One expert stated that the courier sector "will not be able to bear this financially". Another argued that the final form of implementation would depend on regulations and on research concerning the impact of autonomous vehicles on the environment, adding: "I do not think this will be the only form of courier services". The assessment of Thesis 2 therefore suggests that experts recognise environmental pressure, but they do not treat autonomous vehicles as the only path toward sustainable last-mile delivery.

4.2. Expected time horizon and probability of implementation

The probability assessments complement the significance results. Experts did not expect the analysed theses to be implemented in the short term. The implementation horizon was usually shifted beyond 2035, especially for the thesis concerning the inclusion of autonomous vehicles in courier fleets. This confirms that autonomous vehicles were perceived as a future possibility rather than an immediate market change.

The most favourable probability assessment concerned Thesis 4. The results are presented in Figure 1.

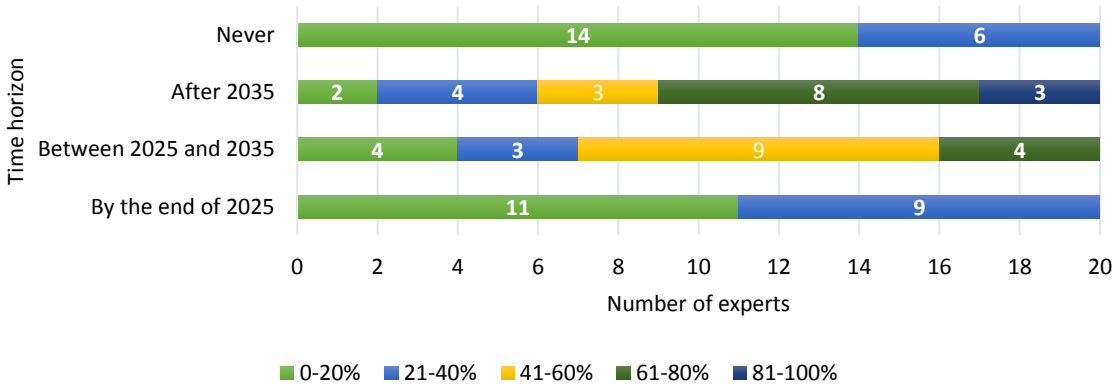

Figure 1. Probability and expected time horizon for Thesis 4. Autonomous vehicles will be part of courier companies' fleets

Source: Authors' own study based on the Delphi study.

For Thesis 4, more than half of the experts assessed the probability of implementation after 2035 in the range of 61-100% (55%). At the same time, most experts considered the "never" scenario unlikely, as 70% assigned it a probability of only 0-20%. This means that experts did not reject the future inclusion of autonomous vehicles in courier fleets. They located this process mainly in the long-term perspective.

The open-ended justifications explain this assessment. One expert wrote that "autonomous technology is already being tested by many logistics companies". Another noted that current technological conditions do not yet allow courier companies to use autonomous vehicles on a wider scale, but "this may change in the more distant future, depending on the economic situation and regulations". The same cautious optimism appears in the statement that

autonomous vehicles may be useful in selected contexts, for example in rural areas where the depot is far away, provided that the vehicle capacity is sufficient.

The sceptical arguments were also clear. One respondent stated that "no autonomy will replace a courier who can work despite various situations that will prevent an autonomous vehicle from completing the task". Another argued that "a bicycle will be cheaper and faster". These comments suggest that experts did not understand fleet adoption as full automation. They rather considered the possibility of using autonomous vehicles in specific delivery segments where their limitations can be controlled.

The assessment of Thesis 3 shows a stronger role of uncertainty. The results are presented in Figure 2.

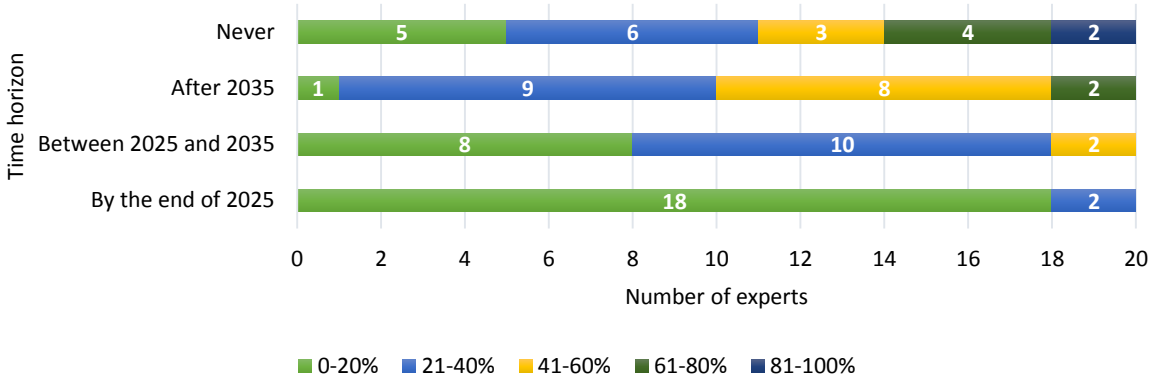

Figure 2. Probability and expected time horizon for Thesis 3. City regulations and transportation policies in large metropolitan areas will eliminate the remaining delivery options other than autonomous vehicles

Source: Authors' own study based on the Delphi study.

For Thesis 3, implementation by the end of 2025 was assessed as highly unlikely. Most experts assigned this time horizon a probability of 0-20% (90%). For the period after 2035, the opinions were more dispersed, and half of the experts assigned the thesis a probability of at least 41%. This indicates that the regulatory scenario was not rejected, but it was treated as uncertain and dependent on long-term policy development.

The qualitative comments confirm this interpretation. One expert wrote that "regulations and their implementation, as well as companies' adaptation to them, will take a long time". Another respondent suggested that such regulations may never be implemented in this form, because "simpler emission-related solutions may be introduced more quickly". A third expert stated briefly that "price will kill the market". These comments point to two important limitations of the regulatory scenario: the slow pace of institutional change and the economic burden imposed on courier companies.

The probability assessment of Thesis 1 also indicates a long-term horizon. The results are presented in Figure 3.

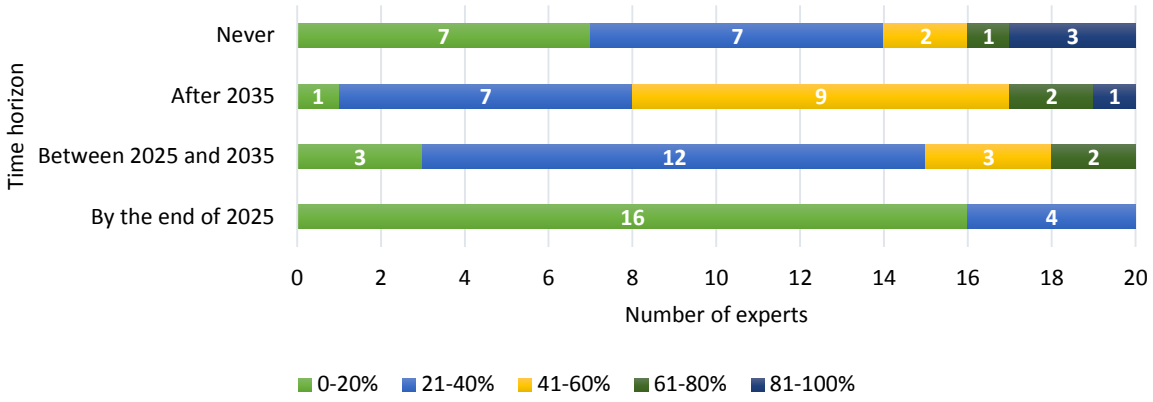

Figure 3. Probability and expected time horizon for Thesis 1. Increased use of autonomous vehicles will result in increased competition among courier companies.

Source: Authors' own study based on the Delphi study.

For Thesis 1, implementation by the end of 2025 was assessed as unlikely by most experts. The probability of implementation in this period was assessed at 0-20% by 80% of experts. In the period after 2035, 60% of experts assigned this thesis a probability of at least 41%. This means that experts perceived a possible future relationship between autonomous vehicles and competition, but they did not see it as an immediate effect.

The experts' comments show that this delay is linked mainly to technological, financial and organisational barriers. One respondent stated that "autonomous vehicles currently have too many weaknesses to be implemented in parcel distribution systems". Another expert noted that courier companies "are only beginning to switch to electric vehicles, so the full transition to autonomous vehicles will take more time". A more technical comment pointed out that autonomous transport requires the development of "AI, machine learning, neural networks and sensors that act as the driver's eyes". Another respondent assessed the probability as low because "driverless vehicles are currently prohibited in the EU". These justifications show that the experts associated the probability of Thesis 1 with the maturity of the whole innovation ecosystem, not only with the availability of vehicles.

Some comments also referred to the risk borne by courier companies. One expert wrote that "no company will bear the costs and responsibility for errors". Another indicated that the implementation of such innovations is unlikely in the near future because of the general economic situation and the lack of public signals that such solutions are ready for broad use. These opinions explain why the experts postponed the possible competitive effect of autonomous vehicles to a longer time horizon.

The most cautious probability assessment concerned Thesis 2. The results are presented in Figure 4.

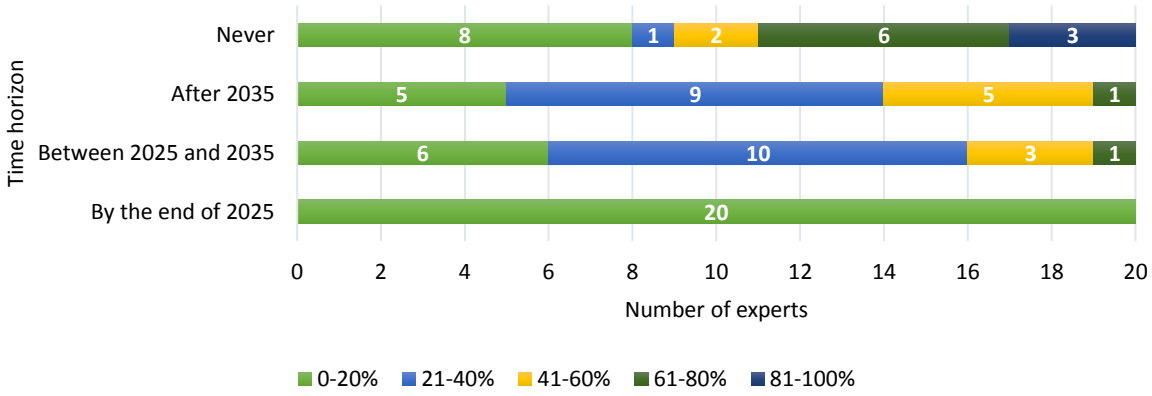

Figure 4. Probability and expected time horizon for Thesis 2. Autonomous vehicles will become the only way to deliver courier shipments consistent with Green Deal policies.

Source: Authors' own study based on the Delphi study.

For Thesis 2, all experts assessed the probability of implementation by the end of 2025 at only 0-20% (100%). For the period between 2025 and 2035, only 20% of experts assigned the thesis a probability of at least 41%. For the period after 2035, this share increased to 30%. This confirms that experts treated the Green Deal-related thesis as the least plausible of the four assessed scenarios.

The qualitative justifications show that the experts considered this thesis both too costly and too exclusive. One respondent wrote: "This is possible, but it requires huge investments". Another stated that "technical possibilities and the economic situation do not allow the introduction of such solutions in the near future". A further comment emphasised that regulations are not introduced quickly and require a long implementation period. Some experts were even more sceptical. One wrote: "I think this will never happen, although there will certainly be people who will try to implement such solutions in a few years". Another stated that "drones with small parcels will come sooner".

At the same time, not all comments were negative. One expert argued that courier companies are obliged to comply with Green Deal policy and that driverless vehicles could reduce delays, increase working hours, reduce human error in delivery and lower fuel costs. This opinion shows that the thesis had some support, but the dominant view was that autonomous vehicles are unlikely to become the only Green Deal-compliant delivery solution.

Overall, the probability assessments are coherent with the significance results. The most plausible scenario is the gradual inclusion of autonomous vehicles in courier fleets. The least plausible scenario is the exclusive use of autonomous vehicles as the only solution compatible with Green Deal policies. The qualitative comments add an important explanation. Experts saw technological potential, but they also pointed to the continued importance of human courier work, delivery flexibility, customer contact, address errors, financial capacity and regulatory readiness.

4.3. Supporting factors

The factors supporting the implementation of the theses were assessed using the favourability indicator. The values are shown in Table 6. The results indicate that the strength of individual factors differs depending on the content of the thesis.

Table 6.
Factors supporting the implementation of the theses

Code	Supporting factor	Thesis 1	Thesis 2	Thesis 3	Thesis 4
S1	Possibility of co-financing the purchase	68.75	78.75	71.25	86.25
S2	Readiness of urban infrastructure	61.25	65.00	81.25	83.75
S3	Development of autonomous vehicle technology	80.00	73.75	75.00	76.25
S4	Level of acceptance of autonomous vehicles	63.75	66.25	67.50	68.75
S5	Ensuring safety	68.75	67.50	76.32	69.74
S6	Legal and regulatory framework	65.00	76.39	83.75	69.74
S7	Compliance with the requirements of the Green Deal	37.50	88.16	44.74	44.74
S8	Ecological awareness and consumer pressure	40.00	57.89	54.17	42.11
S9	Ecological safety related to the construction of an autonomous vehicle	38.89	59.21	47.37	44.74
S10	Progress in research and production of power systems for autonomous vehicles	53.95	69.74	63.89	47.37

Source: Authors' own study based on the Delphi study.

For Thesis 1, the strongest supporting factor was the development of autonomous vehicle technology (80.00). This means that experts linked the possible competitive effect of autonomous vehicles mainly with technological progress. Co-financing and safety were also relevant conditions (68.75 for both factors).

For Thesis 2, the strongest supporting factor was compliance with Green Deal requirements (88.16). This result is consistent with the wording of the thesis. The scenario was also linked with co-financing (78.75), legal and regulatory framework (76.39) and technological development (73.75). This suggests that the Green Deal-related scenario depends on public policy, legal frameworks, financial support and the maturity of autonomous vehicle technology.

For Thesis 3, the highest value was obtained for legal and regulatory framework (83.75), followed by the readiness of urban infrastructure (81.25). This reflects the regulatory nature of the thesis. Experts considered that the influence of city policies on last-mile delivery would depend on the development of legal conditions and on the ability of cities to prepare infrastructure for autonomous delivery.

For Thesis 4, the strongest factor was the possibility of co-financing the purchase (86.25). Urban infrastructure readiness was also highly assessed (83.75), followed by technological development (76.25). This indicates that the adoption of autonomous vehicles by courier companies is conditioned mainly by financial accessibility, infrastructure readiness and technology maturity.

Comparison of the highest-rated supporting factors shows that the scenarios were associated with different enabling conditions. T1 was most strongly associated with the development of autonomous vehicle technology (80.00), T2 with compliance with Green Deal requirements

(88.16), T3 with the legal and regulatory framework (83.75) and urban infrastructure readiness (81.25), and T4 with the possibility of co-financing vehicle purchases (86.25). These results indicate that the dominant enabling condition varied by scenario.

Across the four theses, experts attached the greatest importance to practical implementation conditions. Co-financing, technological development and urban infrastructure were more consistently assessed as relevant than ecological awareness or ecological aspects of vehicle construction. Environmental factors were important mainly in relation to the Green Deal-related thesis. This confirms that the adoption of autonomous vehicles is perceived not only as an environmental issue, but also as a technological, economic, infrastructural and regulatory challenge.

4.4. Barriers to implementation

The barriers to the implementation of the theses were assessed using the barrier indicator. The values are shown in Table 7. The results indicate that financial, legal and operational barriers are the most important for the adoption of autonomous vehicles in urban last-mile courier delivery.

Table 7.
Barriers to the implementation of the theses

Code	Barrier	Thesis 1	Thesis 2	Thesis 3	Thesis 4
B1	Costs of purchasing an autonomous vehicle	73.75	71.25	72.50	85.00
B2	Autonomous vehicle parts disposal costs	56.25	56.25	53.75	62.50
B3	Costs of operating an autonomous vehicle	62.50	53.75	65.00	67.50
B4	Legal barriers	62.50	78.95	80.26	69.74
B5	Insufficient safety and security of technological solutions	51.25	65.79	69.74	65.79
B6	Lack of openness to innovation	53.75	57.89	60.53	61.84
B7	Lack of specialised service points	62.50	52.63	64.47	71.05
B8	Difficulty in getting spare parts	65.00	48.68	58.33	69.74

Source: Authors' own study based on the Delphi study.

The cost of purchasing an autonomous vehicle was the strongest barrier. It received the highest value in relation to Thesis 4 (85.00), but it was also highly assessed for Thesis 1 (73.75), Thesis 3 (72.50) and Thesis 2 (71.25). This shows that experts perceived the initial investment cost as a key limitation for courier companies.

Legal barriers were particularly important for Thesis 3 and Thesis 2. The highest value was obtained for the thesis concerning city regulations and transport policies (80.26), followed by the thesis related to Green Deal-compliant delivery (78.95). This result is coherent with the content of both theses. Autonomous vehicles require clear rules concerning approval for public use, liability, insurance, certification, operating zones and access to public space.

Operational barriers also received high assessments. Lack of specialised service points was particularly important for Thesis 4 (71.05). Difficulty in obtaining spare parts was also assessed as a relevant barrier for fleet adoption (69.74). These findings show that experts considered not

only the purchase of autonomous vehicles, but also their maintenance and operational continuity. The lack of service points and spare-part availability may increase vehicle downtime, disrupt route schedules and reduce the ability of courier operators to maintain promised delivery windows. Consequently, the adoption challenge is not limited to vehicle acquisition but also involves ensuring continuity of daily delivery operations.

The insufficient safety and security of technological solutions was assessed as a meaningful barrier, especially for Thesis 3 (69.74), Thesis 2 (65.79) and Thesis 4 (65.79). This indicates that safety, technical reliability and trust remain important conditions for broader adoption. These concerns may relate to road safety, cybersecurity, interaction with pedestrians and other road users, and the reliability of vehicle control systems.

These findings indicate that the implementation challenge is not limited to the acquisition of autonomous vehicles but extends to the continuity of courier operations. From the perspective of last-mile delivery processes, insufficient service infrastructure and difficulties in obtaining spare parts may increase vehicle downtime, reduce fleet availability and disrupt delivery schedules. As a result, the reliability and timeliness of courier services may be negatively affected, which is particularly important in urban logistics where delivery performance and customer expectations are critical operational factors.

The lack of openness to innovation received moderate values. It was not perceived as the strongest barrier, but it may slow down implementation when combined with high costs, unclear regulations and limited service infrastructure.

5. Discussion

The Delphi study indicates that the adoption of autonomous vehicles in urban last-mile courier delivery should be understood as an evolutionary process rather than a rapid technological substitution. Experts perceived autonomous vehicles primarily as a future component of courier fleets. They did not treat them as the only possible form of last-mile delivery. This finding is consistent with the literature on last-mile logistics, which increasingly presents urban delivery as a system of complementary solutions. Parcel lockers, pickup points, cargo bikes, electric vans, autonomous robots and other delivery models may coexist, depending on the density of demand, urban form, delivery time requirements and customer preferences (Boysen et al., 2021; Ranieri et al., 2018; Savelsbergh, van Woensel, 2016).

This interpretation is important because discussions on autonomous delivery are often technology-centred. The results of the Delphi study suggest a more conditional view. Autonomous vehicles may support courier companies, but their usefulness will depend on the specific operational context. In dense urban areas, their role may be different from that in suburban districts, campuses, logistics parks or controlled delivery zones. This is in line with

studies showing that the efficiency of autonomous delivery robots depends on route structure, delivery density, vehicle capacity, speed, range and integration with depots or micro-hubs (Jennings, Figliozzi, 2019; Ostermeier et al., 2022).

The findings also show that technological maturity alone is not sufficient for adoption. Experts linked the future use of autonomous vehicles with urban infrastructure, public support, legal conditions and operational readiness. This confirms the systemic character of autonomous last-mile delivery. Vehicles must be able to operate safely in public space, communicate with infrastructure, respond to changing traffic conditions and interact with pedestrians, cyclists and other road users. Previous reviews of autonomous delivery systems point to similar implementation conditions, especially infrastructure readiness, safety, stakeholder cooperation and regulatory clarity (Alverhed et al., 2024; Engesser et al., 2023).

The economic dimension is central to the interpretation of the results. Autonomous vehicles may reduce some operating costs in the long term, but their implementation requires high initial investment. For courier companies, the decision will not be based only on the purchase price. It will also depend on maintenance, software updates, supervision, insurance, spare parts, service availability and vehicle downtime. This explains why financial support was perceived as a relevant condition of adoption. Public co-financing may reduce the entry barrier at the testing stage, but it does not remove the need to demonstrate a viable business model.

The operational barriers identified by experts deserve particular attention. The lack of specialised service points and difficulties in obtaining spare parts show that autonomous delivery requires more than access to vehicles. It requires a service ecosystem. Courier companies operate under strong pressure of time, reliability and delivery continuity. If autonomous vehicles cannot be repaired quickly, or if their components are difficult to obtain, they may increase operational risk. This is especially relevant in courier services, where even short disruptions may affect service quality and customer satisfaction.

Legal and regulatory conditions also play a decisive role. Autonomous vehicles cannot be implemented at scale without clear rules on vehicle approval, liability, insurance, access to roads or sidewalks, operating zones and safety standards. This is particularly important in cities, where public space is shared by many users and where local authorities regulate mobility, parking, curb access and low-emission transport. The literature on autonomous delivery robots confirms that legal uncertainty remains one of the main barriers to wider implementation (Hoffmann, Prause, 2018; Sindi, Woodman, 2020).

The Green Deal-related findings should be interpreted with caution. Experts did not support a scenario in which autonomous vehicles become the only delivery solution consistent with environmental policy objectives. This does not mean that autonomous vehicles are irrelevant for sustainable logistics. Rather, it suggests that sustainability in last-mile delivery cannot be reduced to one technology. The environmental effect of autonomous vehicles depends on propulsion type, electricity sources, production processes, battery systems, load factors, routing and vehicle utilisation. Life-cycle studies show that low-emission delivery solutions should be

assessed across the whole delivery system, not only during the operational phase (Figliozzi, 2020; Lemardelé et al., 2023; Temporelli et al., 2022).

The social dimension is also relevant. The implementation of autonomous delivery vehicles requires trust from customers, residents, city authorities and courier companies. Trust in technology depends on perceived usefulness, safety, reliability and risk. Ejdys (2017) emphasises that trust becomes particularly important when users depend on technologies whose operation they cannot fully control. This is applicable to autonomous delivery. Customers must trust that the vehicle will deliver the parcel safely, while city users must trust that it will behave predictably in shared urban space. Studies on the acceptance of autonomous delivery vehicles also confirm the importance of perceived risk, usefulness and trust (Kapser, Abdelrahman, 2020; Yuen et al., 2022).

The removal of the human courier from the delivery process may create additional service challenges. Last-mile delivery is not only a transport task. It also includes communication with the recipient, reaction to wrong addresses, failed delivery attempts, access problems and unexpected customer behaviour. Autonomous vehicles may perform well in standardised conditions, but courier services often require flexibility. This means that autonomous vehicles may first be introduced in delivery contexts where uncertainty is lower and the delivery process can be better controlled.

The Delphi results therefore support a gradual adoption pathway. Autonomous vehicles may first appear in pilot projects, controlled areas and selected delivery segments. Their broader use will depend on the ability to integrate them with existing courier systems. A mixed model seems more realistic than full replacement. In such a model, autonomous vehicles may cooperate with conventional vans, electric vehicles, cargo bikes, parcel lockers and micro-hubs. From a managerial perspective, the results suggest that courier companies should not treat autonomous vehicles as an isolated innovation. They should assess them as part of fleet strategy, network design and service quality management. From a policy perspective, the findings point to the need for urban testing frameworks, clear legal rules and infrastructure adapted to new delivery technologies. Public support may be useful, but it should be connected with safety, environmental performance and organisational reliability.

6. Conclusions

The purpose of this paper was to assess the adoption prospects of autonomous vehicles in urban last-mile courier delivery. The study was based on a qualitative Delphi approach. It focused on expert assessments of four future-oriented theses, supporting factors and barriers. The findings show that experts perceive autonomous vehicles as a possible future component of courier companies' fleets. The highest significance indicator was obtained for the thesis that

autonomous vehicles will be part of courier companies' fleets. This result suggests a gradual and selective adoption path. It does not indicate that autonomous vehicles will replace all other last-mile delivery solutions in the short term. The results also show caution toward more radical scenarios. Experts were less convinced that autonomous vehicles will become the only delivery solution consistent with Green Deal policies. They were also cautious about the thesis that urban regulations will eliminate all other delivery options. The data support a cautious, long-term fleet-diversification scenario. In the short term, autonomous vehicles are more likely to complement than replace existing last-mile delivery solutions. This means that autonomous vehicles should be considered as one element of a broader transformation of urban last-mile delivery. This transformation may also include electric vans, cargo bikes, parcel lockers, pickup points and better delivery consolidation.

The most important supporting factors were the development of autonomous vehicle technology, the possibility of co-financing purchases and the readiness of urban infrastructure. These results indicate that adoption will depend not only on technological maturity. It will also depend on financial accessibility and the ability of cities to create suitable operating conditions. Public support may be important, especially at the stage of testing and early implementation.

The main barriers were the cost of purchasing autonomous vehicles, legal uncertainty, insufficient safety and security of technological solutions, lack of specialised service points and difficulty in obtaining spare parts. These barriers are practical and institutional. They show that courier companies need more than access to autonomous vehicles. They also need clear regulations, reliable maintenance systems, spare parts supply and safe operating rules in urban space.

The study has practical implications for courier companies, city authorities and policymakers. The recommendations presented below represent the authors' interpretation of the Delphi findings rather than direct statements made by the expert panel. Courier companies should assess autonomous vehicles as part of mixed fleet strategies rather than as a single replacement technology. City authorities should prepare conditions for safe testing, including infrastructure, public-space rules and cooperation with logistics operators. Policymakers should consider financial instruments that reduce entry barriers, but such support should be linked to safety, environmental performance and organisational reliability.

The study has several limitations. The Delphi panel was limited in size. The results should therefore be interpreted as an exploratory expert assessment, not as a statistically representative market forecast. The study did not directly measure substitution effects between delivery modes. The study presents findings from the Delphi study and does not include a formal measurement of consensus or stability of expert opinions. The use of indicators helped to organise expert assessments, but the qualitative character of the Delphi method remains central.

Future research should involve a larger and more diverse expert panel. It would be useful to compare the views of courier companies, technology providers, city authorities, researchers and users of delivery services. Further studies may also include additional Delphi rounds,

comparative research between cities or countries, and case studies of pilot implementations. Future research should also examine the economic feasibility, environmental effects and social acceptance of autonomous vehicles in urban last-mile delivery.

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BARRIERS TO ARTIFICIAL INTELLIGENCE IN ORGANISATIONAL INTERNAL CONTROL: BEHAVIOURAL AND TECHNOLOGICAL PERSPECTIVES

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Purpose: The aim of this paper is to identify and systematise the behavioural and technological barriers that limit the effectiveness of artificial intelligence (AI) implementations in organisational internal control systems, and to evaluate the implications of these barriers for regulatory compliance under the European Artificial Intelligence Act (EU AI Act).
Design/methodology/approach: A systematising critical literature review informed by PRISMA methodology was conducted. The databases Scopus, Web of Science, and Google Scholar were searched using keyword combinations spanning AI technology and behavioural psychology. Foundational works from 1995-2015 were included via snowballing, while the primary query targeted publications up to 2025. Following the application of inclusion and exclusion criteria, 22 publications were selected for in-depth qualitative analysis.
Findings: Two principal and mutually opposing psychological mechanisms were identified as the dominant barriers: automation bias — the tendency of auditors to uncritically accept algorithmic recommendations while suspending professional scepticism — and algorithm aversion — the irrational rejection of AI systems following the observation of even minor errors. Organisational culture and auditors' behavioural capital serve as key moderators. The technological barrier of model opacity compounds these behavioural dysfunctions by undermining conditions for informed human oversight as mandated by EU AI Act Article 14.
Research limitations/implications: The study relies on a systematising review of 22 secondary sources without primary empirical data. Future research should empirically verify de-biasing training effectiveness under controlled audit conditions.
Practical implications: Organisations deploying AI in internal control should prioritise Explainable AI (XAI) systems and develop enabling organisational cultures that support professional scepticism. Parallel investment in technology and cognitive competences of audit personnel is essential.
Social implications: Inadequate management of human–AI interaction may lead to a compliance illusion, wherein human oversight is formally satisfied but substantively hollow, exposing organisations and the public to systemic risk.
Originality/value: The study integrates dispersed findings from automation psychology, accounting information systems, and EU regulatory analysis into a unified analytical

framework. It demonstrates that the EU AI Act's human oversight mandate cannot be meaningfully fulfilled without addressing cognitive barriers of system users.
Keywords: automation bias, algorithm aversion, artificial intelligence, internal control, EU AI Act.
Category of the paper: Conceptual paper / Literature review.

1. Introduction

The implementation of artificial intelligence (AI) in risk management, auditing, and internal control processes currently represents one of the most dynamically developing areas of digital transformation in contemporary organisations. Traditional control methods, relying largely on statistical sampling and retrospective analysis of documentation, are becoming insufficient in the face of the growing volume, volatility, and velocity of financial and operational data generation. In response to these challenges, organisations are increasingly implementing advanced analytical systems based on machine learning (ML), natural language processing (NLP), and robotic process automation (RPA). These systems offer the potential to transition from sampling-based control to continuous auditing, analysing the entire population of transactions in real time and enabling proactive identification of anomalies (Boritz, No, 2015; Kokina, Davenport, 2017).

Nevertheless, a growing body of research documents what may be termed the "paradox of algorithmic control": increasing capital expenditures on sophisticated analytical technology do not translate proportionally into an actual improvement in the effectiveness of detecting irregularities and preventing fraud (Streatfield, 2001; Kokina et al., 2025). On closer examination, the weakest link in the modern architecture of control systems is not the technology itself, but the human–algorithm interface, burdened by primary behavioural and cognitive barriers.

At the root of this paradox lie two opposing, though often coexisting, psychological phenomena. On the one hand, automation bias — the propensity of decision-makers to uncritically accept algorithmic recommendations while reducing professional scepticism (Parasuraman, Manzey, 2010). On the other hand, algorithm aversion — the complete rejection of supporting technology following the observation of even a single, marginal error, despite the system's aggregate predictive accuracy significantly exceeding that of human judgement (Dietvorst, Simmons, Massey, 2015).

Managing these mechanisms becomes critical given the regulatory environment. The EU AI Act (Regulation 2024/1689) categorises systems used for financial and operational risk management as "high-risk", imposing an obligation to ensure effective human oversight. This requirement, however, appears difficult to fulfil without first diagnosing and neutralising the cognitive barriers of system users: automation bias renders human oversight illusory,

reducing it to mechanical approval of algorithmic outputs — a phenomenon that may be termed compliance illusion.

Despite extensive separate research streams on automation psychology, accounting information systems, and AI regulation, the literature lacks an integrative framework that simultaneously addresses all three dimensions in the context of internal control. This gap is particularly acute in the Central European context, where organisations face the dual challenge of rapid AI adoption and compliance with the EU AI Act without established traditions of enabling organisational culture.

The aim of this article is to identify and systematise the behavioural and technological barriers limiting the effectiveness of AI implementations in internal control systems. Specifically, the study addresses the following research questions:

RQ1: What are the principal behavioural mechanisms that impair the effectiveness of AI-supported internal control, and how do automation bias and algorithm aversion manifest in audit environments?

RQ2: How does organisational culture — specifically the distinction between enabling and coercive bureaucratic models — moderate the intensity of behavioural barriers to AI adoption in control processes?

RQ3: To what extent do existing regulatory frameworks, particularly the EU AI Act's human oversight requirement, address the identified behavioural and technological barriers, and what are the conditions for their effective implementation?

The contribution of this paper lies in integrating dispersed findings from automation psychology with the latest regulatory challenges and the specificity of internal controllers' work, thereby formulating a coherent analytical framework for managing technological change in audit units (Raisch, Krakowski, 2021).

2. Methods

The paper was prepared on the basis of a systematising critical literature review informed by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology. Given the interdisciplinary nature of the investigation — spanning behavioural psychology, accounting information systems, organisational management, and EU regulatory analysis — a multi-source search strategy was adopted to ensure comprehensive coverage of the relevant scholarly discourse.

The primary databases searched were Scopus and Web of Science Core Collection, which were selected for their extensive coverage of international peer-reviewed literature in the fields of management, accounting, and information systems. In addition, Google Scholar was

searched to capture Polish-language monographs and regulatory sources from the domain of management sciences that are not fully indexed in the aforementioned international databases.

The search strategy employed keyword combinations designed to bridge the technological and behavioural dimensions of the research problem. The following terms were used in various Boolean combinations: "internal control" OR "audit" combined with "artificial intelligence" OR "automation" combined with "behavioral" OR "trust" OR "algorithm aversion" OR "automation bias" OR "moral disengagement". The primary temporal scope of the query encompassed recent literature up to 2025, reflecting the rapidly evolving nature of AI technology and its regulatory environment. However, foundational works from the period 1995-2015 — particularly seminal contributions establishing the theoretical underpinnings of automation bias (Parasuraman, Manzey, 2010), algorithm aversion (Dietvorst, Simmons, Massey, 2015), organisational trust (McAllister, 1995), and bureaucratic typologies (Adler, Borys, 1996) — were incorporated through a snowballing procedure to ensure theoretical completeness.

The inclusion criteria encompassed: (a) peer-reviewed scientific articles published in English or Polish; (b) academic monographs with established citation reputation; (c) official reports and standards issued by internationally recognised professional bodies (specifically the IIA and ICAEW); and (d) key legislative instruments directly relevant to AI governance in the European context (EU AI Act). Exclusion criteria were applied to filter out purely computational or engineering-oriented publications focused exclusively on algorithmic optimisation, neural network architecture, or hyperparameter tuning, which lacked any substantive engagement with the managerial, behavioural, or organisational dimensions of AI implementation.

Following the systematic application of these criteria, 22 publications were selected for in-depth qualitative analysis. The analytical approach was based on deductive content coding, which enabled the grouping of identified barriers into two overarching categories: technological barriers (centred on the problem of model explainability) and behavioural barriers (encompassing dysfunctional trust patterns in human–algorithm interaction). An additional analytical layer involved triangulating findings from the scholarly literature with the normative requirements defined in Regulation (EU) 2024/1689. The complete list of 22 sources constituting the empirical foundation of this review is provided in the References section of this paper.

3. Results

3.1. Technological barriers: model opacity and the explainability imperative

The analysis of the selected sources indicates that artificial intelligence brings unprecedented transformational potential to the internal control environment. Traditional oversight systems relied on sampling methods where random data selection prevailed. In organisations processing millions of transactions daily, reliance on a sample of several dozen documents carries substantial risk of failing to detect systemic financial anomalies. AI-class systems and advanced machine learning algorithms enable the implementation of a continuous assurance model, which monitors the entire population of phenomena in the enterprise in real time, automatically categorising them according to risk level (Boritz, No, 2015).

Nevertheless, the implementation of this potential immediately encounters a critical technological barrier. The literature on accounting information systems consistently emphasises that AI adoption in audit units is impeded by the problem of model opacity, commonly known as the "black box" problem. Complex algorithms — in particular deep learning neural networks — generate recommendations based on multidimensional correlation analyses that remain entirely illegible to the human cognitive apparatus (Rudin, 2019). In the domain of financial audit and risk assessment, the inability to reconstruct the logic underlying an algorithmic decision disqualifies such tools in the eyes of professionals who bear ultimate criminal and disciplinary responsibility for control conclusions (Zhang, Cho, Vasarhelyi, 2022).

This limitation has prompted the formulation in the literature of a postulate to develop and deploy only algorithms from the Explainable AI (XAI) category. Such systems, in addition to generating the outcome itself (e.g., "transaction flagged as potential fraud"), provide the auditor with substantive justification and a transparent list of weighting factors that led to the conclusion. Without adherence to the principle of output transparency, technological tools risk becoming a source of new, poorly understood risks in the compliance environment (Kokina et al., 2025).

3.2. Automation bias: the erosion of professional scepticism

The results of the literature analysis demonstrate that behavioural factors constitute the principal predictor of AI system failure in risk management. The phenomenon of automation bias consists in the unreflective tendency of decision-makers to approve suggestions originating from automated systems while simultaneously lowering criticism towards these recommendations (Parasuraman, Manzey, 2010). In audit and compliance units, this mechanism assumes a particularly dangerous form: auditors, operating under chronic time pressure, treat positive algorithmic evaluations as definitive confirmation of the absence of irregularities, ultimately refraining from independent verification activities. Routine interaction

with the system leads to what the literature terms complacency error — the progressive atrophy of active monitoring skills.

The ICAEW (2024) has identified over-reliance on automation as one of the greatest contemporary sources of audit risk. Employees subjected to intensive algorithmic supervision lose a sense of individual agency, which directly diminishes their initiative and capacity to detect unconventional anomalies that the model has not been trained to recognise (Kellogg, Valentine, Christin, 2020). In environments characterised by excessive algorithmic signal generation — a condition known as alert fatigue — the mechanical dismissal of alerts becomes commonplace, entirely defeating the purpose of the automated system (Munoko, Brown-Liburd, Vasarhelyi, 2020).

3.3. Algorithm aversion: the asymmetry of error tolerance

At the opposite pole of the behavioural spectrum, the literature identifies algorithm aversion. Experimental research demonstrates that system users tend to disproportionately penalise machines for errors. Dietvorst, Simmons, and Massey (2015) established that individuals lose trust in AI-based systems with extreme rapidity upon observing even a single obvious error. Paradoxically, the same level of error produced by a human expert is tolerated as a "human factor", whereas absolute infallibility is subconsciously demanded of algorithms.

In audit departments, algorithm aversion manifests as an effective nullification of system utility and its silent boycott by working teams. Even when a machine learning model achieves a 95% accuracy rate — far exceeding traditional human capabilities in large-scale data analysis — a single false positive suffices to discourage professionals from further engagement with the system (Benbya, Pachidi, Jarvenpaa, 2021). This dynamic is compounded by progressive deskilling: as auditors less frequently perform independent data evaluation, they become increasingly inclined to reject algorithmic conclusions in ambiguous situations.

The phenomenon stands in fundamental contradiction to the postulates of Human-Centered AI design (Shneiderman, 2022). A properly designed control system should stimulate active trust calibration: auditors must be trained to understand the boundaries of algorithmic utility and to rationally assess when human judgement should override machine recommendations, rather than wholesale rejecting the platform following isolated errors.

3.4. Organisational culture as a moderator of behavioural barriers

The intensity of both mechanisms described above is critically modulated by the organisational context. In the classic bureaucratic typology formulated by Adler and Borys (1996), organisations grounded in coercion (coercive bureaucracy) enforce unquestioning submission to technological standards, thereby amplifying automation bias. Employees in such systems use algorithms as a protective shield that relieves them of personal responsibility for control outcomes. This contrasts with enabling models (enabling bureaucracy), in which employee knowledge and human capital are prioritised, and the algorithm functions as

a supporting tool that does not supplant the obligation to exercise independent professional judgement (Grzesiak, 2021).

This distinction presupposes the presence of cognition-based trust — a relationship in which the auditor possesses sufficient competence and confidence to challenge decisions produced by the machine (McAllister, 1995). The internal control standards issued by the IIA (2024) explicitly state that professional scepticism remains an inalienable foundation of the auditor's work, and that the responsibility for formulating an opinion can never be transferred to a software system, regardless of its sophistication. A direct implication follows: building organisational resilience in the era of AI depends on trust and the continuous upgrading of competences, not merely on delegating duties to IT systems (Koźmiński, 2004; Bugdol, 2010).

4. Discussion

4.1. Synthesis: the automation–augmentation paradox in internal control

The results presented above converge to illuminate what Raisch and Krakowski (2021) have conceptualised as the automation–augmentation paradox: technology simultaneously possesses the capacity to enhance and to undermine human decision-making, depending critically on the implementation context. In the domain of internal control, this paradox manifests with particular acuity. The very systems designed to augment the analytical power of auditors may, through the mechanisms of automation bias, erode the professional scepticism they were intended to support. Conversely, algorithm aversion may cause organisations to forfeit the genuine analytical advantages that AI systems demonstrably offer.

The evidence gathered in this review indicates that resolving this paradox is not merely a matter of managerial preference or optional organisational improvement but constitutes a pressing regulatory necessity. The EU AI Act (Regulation 2024/1689) categorises software used in broadly understood control infrastructure as high-risk systems. Article 14 of this regulation introduces the concept of mandatory human oversight, requiring entities to guarantee employees' real ability to identify system dysfunctions, override recommendations, or halt the system entirely in emergency situations. An analysis of the literature juxtaposed with this legal requirement reveals a significant pragmatic conflict: human oversight is legally mandated, yet from the perspective of behavioural science, it becomes entirely fictitious in organisations with immature management cultures. An employee who has succumbed to automation bias will approve any system-generated report, formally satisfying the "human oversight" postulate while substantively constituting a circumvention of legislative intent (Szpringer, 2024). This phenomenon — which may be termed compliance illusion — represents a critical gap between regulatory aspiration and organisational reality.

4.2. Organisational context: differential barriers across institutional types

An important dimension insufficiently addressed in the existing literature concerns the variation in AI adoption barriers across different organisational contexts. Three distinct environments merit consideration.

Large financial corporations typically possess substantial resources for AI implementation, including dedicated data science teams and established compliance infrastructure. However, their rigid hierarchical structures and extensive regulatory obligations may foster coercive bureaucratic tendencies (Adler, Borys, 1996). In such settings, automation bias poses the principal risk: auditors operating within highly proceduralised environments may perceive algorithmic recommendations as an extension of institutional authority and thus apply minimal critical scrutiny. The scale and complexity of operations — often spanning multiple jurisdictions — compounds the challenge, as human oversight must be maintained across thousands of automated decisions daily.

Public institutions, including government audit offices and regulatory agencies, face a distinct constellation of barriers. These organisations frequently operate under severe resource constraints, characterised by legacy IT infrastructure and limited access to specialist AI competences. The dominant bureaucratic culture in many public institutions tends strongly toward coercion (Kellogg, Valentine, Christin, 2020), creating an environment in which algorithmic outputs may be uncritically adopted as an efficiency measure rather than a genuine analytical enhancement. Furthermore, the public accountability framework introduces additional complexity: errors attributable to AI systems may generate disproportionate reputational damage, potentially amplifying algorithm aversion among risk-averse public servants.

Small and medium-sized enterprises (SMEs) confront the most acute version of the competence gap identified by Szpringer (2024). Many SME audit departments lack both the tools and the specialised personnel necessary to evaluate AI system compliance with regulatory requirements. For these organisations, the first practical step toward meaningful AI integration is likely to consist of basic XAI literacy training — enabling controllers to pose the right questions about algorithmic recommendations before accepting or rejecting them (Grzesiak, 2021). The informal organisational cultures characteristic of many SMEs may, paradoxically, offer advantages: the absence of deeply entrenched bureaucratic rigidity may facilitate the development of enabling cultures supportive of critical thinking and trust calibration (Bugdol, 2010).

4.3. Explainable AI in audit practice: from postulate to implementation

The consistent call in the literature for Explainable AI (XAI) as a prerequisite for responsible AI deployment in control systems (Rudin, 2019; Zhang, Cho, Vasarhelyi, 2022) raises a natural question regarding concrete implementation mechanisms. Two technical approaches merit particular attention in the context of audit applications.

First, **SHAP (SHapley Additive exPlanations) values (Lundberg, Lee, 2017)** represent a model-agnostic method that enables auditors to understand the contribution of each individual input feature to a specific algorithmic decision. In the context of fraud detection, for instance, a machine learning model that flags a particular transaction as suspicious can, via SHAP analysis, present the auditor with a transparent decomposition of the factors driving the classification — such as transaction amount, counterparty novelty, temporal deviation from established patterns, or geographic anomaly. This granular attribution directly addresses the "black box" problem identified by Rudin (2019), transforming an opaque algorithmic verdict into a structured basis for professional judgement. Crucially, SHAP values enable auditors to exercise the informed scepticism mandated by professional standards (IIA, 2024), as they can evaluate whether the system's reasoning aligns with their domain knowledge of risk indicators.

Second, **locally interpretable model-agnostic explanations (LIME)** offer a complementary approach that generates simplified, human-readable approximations of complex model behaviour for individual predictions. In continuous auditing environments — where AI systems process entire transaction populations in real time (Boritz, No, 2015) — LIME can provide auditors with case-by-case explanations of why specific transactions were escalated for manual review. This mechanism directly mitigates both of the identified behavioural barriers: it reduces automation bias by compelling the auditor to engage with the reasoning behind the recommendation rather than accepting it passively, and it reduces algorithm aversion by making the system's decision logic transparent, thereby allowing users to calibrate their trust based on substantive understanding rather than superficial impressions of system performance (Zhang, Cho, Vasarhelyi, 2022; Shneiderman, 2022).

The deployment of such XAI mechanisms addresses the core requirement of Article 14 of the EU AI Act: effective human oversight presupposes that users "fully understand the capabilities and limitations of the system" (Regulation EU 2024/1689). Without interpretable outputs, this understanding — and consequently genuine human oversight — remains unattainable.

4.4. Regulatory implications: bridging the gap between legal mandate and organisational reality

The regulatory framework established by the EU AI Act provides a normative foundation that, if implemented with due regard for behavioural science, can serve as a catalyst for organisational transformation. The internal control standards issued by the IIA (2024) reinforce

this position by affirming that professional scepticism remains non-negotiable even in highly automated environments. A direct implication for management follows: security management in the AI era is fundamentally an exercise in building organisational resilience grounded in trust and the continuous development of human competences, rather than in the mere delegation of cognitive duties to software systems (Koźmiński, 2004; Bugdol, 2010).

However, the analysis reveals that regulatory compliance alone is insufficient without corresponding investment in the behavioural dimension. The effective transition from automation to augmentation (Raisch, Krakowski, 2021) requires the simultaneous development of three pillars: (a) a technological pillar, mandating the deployment of XAI-compliant models that provide auditors with actionable explanations; (b) a regulatory pillar, enforcing active and genuine human oversight consistent with EU directives; and (c) a behavioural pillar, developing enabling organisational cultures in which professional doubt is treated not as disloyalty but as a manifestation of mature professionalism. Asymmetric investment — heavy expenditure on AI licenses without corresponding investment in the cognitive capital of the human team — leads to the façade nature of internal control processes and exposes the organisation to significant legal and reputational risk.

5. Conclusions

5.1. Knowledge contribution

This literature review makes three principal contributions to the scholarly understanding of AI implementation in internal control. First, it integrates previously dispersed findings from automation psychology, accounting information systems, and EU regulatory analysis into a unified analytical framework, demonstrating that behavioural, technological, and regulatory barriers are not independent phenomena but mutually reinforcing dimensions of a single systemic challenge. Second, it identifies the compliance illusion — the condition in which the EU AI Act's human oversight requirement is formally satisfied but substantively hollow due to unaddressed cognitive biases — as a critical and under-recognised risk in the digitalisation of control processes. Third, it demonstrates that the enabling–coercive bureaucratic typology (Adler, Borys, 1996) provides a theoretically grounded and practically actionable lens for predicting the differential susceptibility of organisations to automation bias and algorithm aversion.

5.2. Theoretical and practical implications

From a theoretical standpoint, the study advances the automation–augmentation paradox framework (Raisch, Krakowski, 2021) by demonstrating its specific manifestation in the internal control domain, where the stakes of cognitive failure are amplified by legal liability and public accountability. The integration of behavioural mechanisms with regulatory requirements contributes to the emerging literature on human-centred AI governance.

From a practical perspective, the findings yield three recommendations for management and audit leadership. First, organisations deploying AI in control processes should mandate the use of Explainable AI systems — specifically techniques such as SHAP or LIME — that enable auditors to exercise informed professional scepticism rather than passive acceptance or uninformed rejection of algorithmic outputs. Second, management should invest in structured de-biasing training programmes designed to calibrate auditors' trust in AI systems, incorporating simulated error scenarios that develop the capacity to distinguish between meaningful system failures and statistically expected imprecision. Third, organisational leaders should actively cultivate enabling bureaucratic cultures that reward critical questioning and professional doubt, as the review demonstrates that coercive cultures systematically amplify both automation bias and algorithm aversion.

5.3. Limitations

Several limitations of this study must be acknowledged. First, the analysis is based on a systematising review of 22 secondary sources and does not incorporate primary empirical data; consequently, the conclusions, while theoretically robust, require empirical verification in specific organisational settings. Second, the rapid pace of technological change in artificial intelligence means that some of the reviewed sources may not fully capture the most recent developments in model interpretability, real-time auditing capabilities, or regulatory implementation practices. Third, the study relies predominantly on conceptual analysis and theoretical extrapolation from existing literature; the proposed framework has not been tested through large-scale empirical investigation, and the organisational context analysis (Section 4.2) draws on logical inference from established theories rather than direct comparative evidence.

5.4. Future research directions

The direction for further research postulated on the basis of this review should prioritise the experimental verification of the effectiveness of specific de-biasing training interventions aimed at calibrating employees' trust in decision support systems under rigorously controlled conditions of auditors' work. Particularly valuable would be comparative studies examining the differential effectiveness of XAI interventions across organisational types — large financial corporations, public institutions, and SMEs — to validate the contextual framework proposed

in Section 4.2. Additionally, longitudinal studies tracking the evolution of automation bias and algorithm aversion over extended periods of human–AI collaboration would contribute significantly to understanding the temporal dynamics of trust calibration in audit environments.

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SUPPORT FOR ROAD TRANSPORT MANAGEMENT – AI-BASED LEGAL QUESTION ANSWERING: A SEARCH-BASED APPROACH AND PILOT EVALUATION

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Purpose: Road logistics practitioners operate in a complex regulatory environment where compliance information is dispersed across numerous legal documents, making the identification and interpretation of relevant regulations time-consuming and challenging. This study evaluates an AI-based legal question-answering (QA) system that supports regulatory compliance through retrieval-augmented generation (RAG). The objective is to assess whether a lightweight retrieval-grounded approach can provide accurate, traceable, and operationally useful answers without requiring domain-specific model fine-tuning.
Design/methodology/approach: The study adopts a design science and experimental evaluation approach. A domain-specific RAG architecture was developed using a corpus of Polish and European road transport regulations comprising approximately 2365 pages of legal documentation. A dataset of 50 practitioner-oriented legal questions with verified answers and article-level references was constructed for evaluation. The system combines semantic retrieval using vector embeddings and FAISS indexing with large language model-based answer generation. Performance was assessed through retrieval accuracy, answer correctness, citation grounding, and human-in-the-loop prompt refinement experiments.
Findings: The results demonstrate that retrieval-grounded legal QA can effectively support compliance-related information retrieval in road logistics. Under one-shot conditions, the system achieved 59% answer accuracy and 26.3% fully grounded responses. With limited user interaction and prompt refinement, answer accuracy increased to 82% and fully grounded responses to 41%. Many failures were caused by query ambiguity rather than missing knowledge. The findings indicate that retrieval-grounded AI can provide transparent, document-linked responses suitable for operational decision support.
Research limitations/implications: The study is based on a pilot dataset of 50 questions and focuses on Polish and EU road transport regulations. Future research should investigate larger datasets, multilingual retrieval, and user-centered evaluations examining trust, usability, and adoption.

Practical implications: The proposed system can assist logistics managers, dispatchers, compliance officers, and transport operators in locating and interpreting legal requirements more efficiently. Citation-grounded answers improve transparency and support faster regulatory decision-making.
Originality/value: This study introduces one of the first retrieval-augmented legal QA systems specifically designed for road logistics compliance. It contributes a domain-specific Polish road transport QA dataset, a practical RAG-based compliance architecture, and empirical evidence on the feasibility of retrieval-grounded AI for operational regulatory support.
Keywords: Artificial intelligence; Road transport regulations; Road transport management, Retrieval-augmented generation; Compliance support.
Category of the paper: Research paper.

1. Introduction

Logistics plays a central role in supply chain management by creating place utility and ensuring that raw materials and finished goods move efficiently from suppliers to customers across regions and borders. It encompasses interconnected activities such as transportation, warehousing, inventory management, packaging, and information processing, with transport via road, rail, air, waterways, pipelines, and multimodal networks forming the backbone of most operations (Islam et al., 2013).

In the European Union, road freight transport remains the dominant mode, accounting for nearly 1.9 trillion tonne-kilometres annually and supporting the majority of domestic and cross-border trade flows (Eurostat, 2025). Given this scale, road logistics is critical to modern supply chains but is also highly exposed to regulatory, operational, and safety challenges. Similar issues are observed globally; for instance, the Australian road transport sector is characterized by fragmented supply chains, strong cost pressures, and poor safety outcomes, highlighting how complex subcontracting structures can undermine working conditions and complicate effective regulation (Rawling et al., 2017).

Harmonizing regulations across the supply chain is fundamental to building an efficient and sustainable national logistics system. Effective integration requires coordinated action among government, industry, and society to ensure consistent policies and aligned operations (Akbar et al., 2025). Within this environment, understanding legal and regulatory requirements becomes a core operational capability rather than a peripheral administrative task. Empirical evidence shows that compliance with road safety and transport laws enhances supply chain reliability, responsiveness, and agility by reducing accidents, disruptions, and delivery delays (Adu et al., 2023).

More broadly, transport logistics has been characterized as both an economic and legal institution, where freight flows are governed through contracts, regulatory standards, and formal legal frameworks. When these legal structures are weak or unclear, inefficiencies,

disputes, and coordination problems emerge, undermining system performance and sustainability (Filippova, Voronina, 2021). At the same time, many regulatory practices rely heavily on tacit, experience-based knowledge that is difficult to formalize, leading scholars to recommend expert involvement to complement technical analyses and ensure practical relevance (Glistau et al., 2024).

However, legal document understanding itself is challenging due to the growing volume, length, and linguistic complexity of legal texts. Regulations, contracts, and policies often contain specialized terminology and formal structures that require expert interpretation, making manual analysis time-consuming even for professionals. For logistics practitioners who must make rapid operational decisions, this complexity creates substantial cognitive and practical burdens. Consequently, automated approaches such as summarization, retrieval, and QA are increasingly necessary to support efficient and reliable decision-making (Quevedo, 2023).

Recent advances in artificial intelligence (AI), particularly large language models (LLMs), offer promising opportunities to address these limitations. Nevertheless, evidence suggests that general-purpose LLMs alone remain insufficient for legal question answering (QA), as they often generate overly generic responses, lack logical specificity, and may hallucinate information, potentially exposing users to legal and financial risks. Retrieval-augmented generation (RAG) approaches have therefore emerged to ground LLM outputs in relevant legal documents and cases, improving factual accuracy and reducing hallucinations (Yao et al., 2025). RAG is an AI framework that improves LLM outputs by retrieving relevant information from external knowledge sources to ground responses in accurate, up-to-date, and verifiable facts (Martineau, 2023).

Recent legal QA research demonstrates rapid progress in retrieval-augmented and LLM-based assistance across multiple jurisdictions and legal domains but also reveals recurring limitations. Several studies introduce domain and language-specific datasets and benchmarks, such as criminal-law QA in India with practitioner-informed evaluation (Nigam et al., 2023), and Thai legal QA benchmarks focusing on financial and tax law while systematically comparing RAG pipelines and long-context alternatives (Akarajaradwong et al., 2025a, 2025b).

In China, LeDQA provides long case-document QA with a professional question schema and sentence-level relevance annotations (Liu et al., 2024). Other work targets longer, explanatory answers and interpretability, proposing reasoning-first generation and semi-synthetic long-form QA datasets (Ujwal et al., 2024), and showing that improving legal QA often requires more than semantic matching by integrating logical structures with retrieval and generation (Yao et al., 2025). Complementary Polish-language studies examine complex multi-step reasoning datasets (Wojtasik et al., 2025), retrieval from lay statements to statutory provisions and the effects of fine-tuning retrieval models (Smywiński-Pohl et al., 2025), and explainable clause retrieval over a civil-code knowledge base (Matak, Chudziak, 2025).

Finally, systematic evidence from broader Legal NLP literature emphasizes that legal QA, summarization, and retrieval remain data and evaluation-constrained, and that curated datasets and robust grounding are central bottlenecks (Quevedo et al., 2023).

However, despite these advances, none of the existing systems specifically address the operational needs of road logistics compliance. Therefore, across these studies, three gaps are especially relevant for road logistics. First, most benchmarks focus on general legal domains (civil/criminal/tax, procurement, case law) rather than operational transport compliance, where users need fast, actionable answers linked to specific regulations (Nigam et al., 2023; Akarajaradwong et al., 2025a, 2025b; Liu et al., 2024; Karp et al., 2025).

Second, many evaluations remain offline and benchmark-driven (e.g., exam-style multiple choice or synthetic QA), and results repeatedly highlight persistent issues with hallucinations, incorrect citations, and brittle reasoning, especially for longer or judgment-style outputs, suggesting that system usefulness must be assessed in more assistive, user-facing settings (Karp et al., 2025; Ujwal et al., 2024; Yao et al., 2025).

Third, legal RAG performance is highly dependent on the availability of task-appropriate QA data; however, transport-specific datasets remain largely absent, particularly for road transport regulations and practitioner-oriented questions reflecting dispatcher or logisticsmanager decision contexts (Quevedo et al., 2023; Smywiński-Pohl et al., 2025).

Moreover, legal QA is inherently complex and data-intensive, while existing benchmark datasets are predominantly large, expert-annotated collections developed in English or Asian languages and focused on domains such as judicial decisions, contracts, or privacy law rather than operational transport regulations, creating a clear gap for Polish road-logistics compliance applications (Abdallah et al., 2023).

Leveraging these insights and addressing the identified gaps, we focus on road-transport compliance as an under-served but operationally critical setting for legal QA. We develop and evaluate a domain-specific, Polish-language, retrieval-grounded QA system that supports practitioners in locating and interpreting relevant provisions with transparent evidence links. To enable an evaluation aligned with realistic logistics decision-making, we curate a focused dataset of 50 road-transport legal questions and answers reflecting practitioner-style queries. Accordingly, we address the following research questions:

RQ1. *How can AI-based legal question answering be developed for Polish-language logistics and transport regulations, where no domain-specific systems currently exist?*

RQ2. *How accurately does the proposed RAG system retrieve the relevant legal basis and generate citation-grounded answers on a curated set of Polish road-transport compliance questions?*

Beyond addressing the research questions, this study contributes to the emerging intersection of logistics and legal AI by positioning legal QA within an operational compliance context rather than another legal QA benchmark. Specifically, we introduce a domain-specific

Polish road-transport QA dataset composed of practitioner-style, citation-grounded questions reflecting real logistics decision scenarios. Moreover, The originality of this study lies in its focus on road logistics compliance, a domain largely overlooked in existing legal QA research.

Our results provide empirical evidence that a lightweight retrieval-augmented architecture can support regulatory QA without domain-specific fine-tuning or large annotated corpora. Hence, the study reframes legal QA as an assistive decision-support tool for dispatchers and logistics managers and provides empirical insights into how linguistic specificity and jurisdictional cues influence retrieval behavior in multi-layered regulatory environments. Moreover, our results show that failures arise primarily from query formulation ambiguity rather than retrieval absence, indicating that interactive clarification is a structural requirement of regulatory QA systems.

The originality of the study lies in (1) developing a domain-specific RAG-based legal QA system for road logistics regulations, (2) constructing a practitioner-oriented Polish road transport QA dataset with verified legal references, and (3) empirically evaluating retrieval accuracy, answer correctness, and citation grounding in a real compliance-support setting. By positioning legal QA as an operational decision-support tool rather than solely a benchmark task, the study extends current research on legal AI and logistics compliance.

The rest of the paper is organized as follows: The *Literature Reviews* section presents related work on regulatory complexity in road logistics and retrieval-augmented legal QA. The *Methodology and Experimental Setup* section presents the methodology and experimental setup, including dataset construction, the RAG system architecture, and the evaluation framework and results. The *Discussion* section discusses the findings, and the *Conclusion* section concludes the paper. Finally, the *Future Direction* section outlines directions for future work.

2. Literature Review

Logistics and road transport operations increasingly function at the intersection of operational efficiency, regulatory compliance, and digital transformation. As supply chains become more global and interconnected, firms must simultaneously manage complex transport processes, evolve legal requirements, and adopt new digital technologies.

These developments have elevated regulatory knowledge and information management from peripheral administrative tasks to core operational capabilities. At the same time, advances in AI and data-driven systems are reshaping how logistics decisions are supported and executed. Against this backdrop, existing research spans three interrelated streams: regulatory and legal complexity in logistics practice, AI and retrieval-based approaches for legal QA, and technology acceptance factors influencing the adoption of digital decision-support tools.

Reviewing these streams together provides the foundation for understanding why intelligent, assistive systems are increasingly necessary to support compliance and decision-making in road logistics.

2.1. Regulatory Complexity and Decision-Making Challenges in Road Logistics

Globalization and increasingly complex supply chains have made logistics and customs management central to the efficiency and compliance of international transport operations. While digital technologies such as automation, blockchain, and AI improve operational performance, their integration poses new challenges in meeting evolving regulatory and standardization requirements (Orłowska, Chackiewicz, 2024).

Social legislation in road transport seeks to protect drivers' working conditions and improve safety, yet EU and AETR rules are often perceived as complex and difficult to interpret. Compared with other countries, these regulatory burdens can hinder compliance and may even negatively affect road safety, highlighting the need for clearer and more supportive decision tools (Poliak et al., 2018).

Moreover, road logistics operates within a complex, multi-layered regulatory environment where compliance is not optional but foundational to effective operations. Evidence shows that companies cannot function efficiently without being aware of and integrating legal, governmental, and transport regulations into daily practices. Transportation and logistics laws directly shape supply chain performance, costs, and reliability, making regulatory knowledge a core operational competence rather than a peripheral requirement (Mutangili, 2019).

Similarly, previous research emphasize that legal transport operations are also governed by formal documentation requirements and evidentiary rules defined under national law and international conventions such as Convention on the Contract for the International Carriage of Goods by Road (CMR) and Uniform Rules Concerning the Contract of International Carriage of Goods by Rail (CIM) (Garnowski, 2017).

Beyond structural complexity, compliance challenges translate into tangible operational risks. Legal misunderstandings may lead to inspections, fines, shipment delays, and contractual liabilities. Sector-specific legal frameworks, such as national commercial goods transport law, further demonstrate the formal and codified legal structures governing freight, forwarding, and warehousing activities under domestic and international provisions (Walther, 2008).

It should also be noted that both EU and Polish regulations do not provide for uniform legal regulations covering all modes of transport. In the case of Polish legal regulations, the most general regulations concerning the transport of persons and goods are contained in the Civil Code. The provisions of the Civil Code in this regard (Odzimek, 2023). Consequently, day-to-day logistics decision-making frequently depends not on formal legal analysis but on tacit, experience-based knowledge accumulated by dispatchers and managers.

In addition, educational perspectives emphasize that legal literacy is a necessary competence for logistics professionals, as daily activities rely heavily on contracts, liability rules, and international regulations such as CMR and INCOTERMS (Odzimek, 2023). However, in practice, operators often work under time pressure and rely on experience-based judgments rather than systematic consultation of legal texts, which may increase the risk of non-compliance.

Recent developments in digital technologies suggest potential solutions to operational complexity in logistics. Bibliometric evidence indicates growing interest in the use of AI for decision-making support, process automation, and data-driven optimization in supply chains (Marchewka, Cierzniewska, 2025).

Leveraging these developments, AI-based tools may also assist practitioners in navigating complex regulatory information by improving retrieval, interpretation, and transparency of legal knowledge. Additionally, the literature suggests that regulatory complexity, operational risk, and tacit knowledge gaps collectively justify the development of AI-assisted legal QA systems tailored specifically to logistics practice.

2.2. Retrieval-Augmented Generation for Legal Question Answering

AI is increasingly reshaping legal practice, with natural language processing (NLP) and LLMs supporting tasks such as legal document analysis, contract review, case prediction, legal research, and regulatory compliance. Recent studies report rapid growth in both the number and sophistication of these applications, highlighting the expanding role of AI as a practical decision-support tool for legal professionals (Siino et al., 2025). Despite enabling powerful QA capabilities, recent LLMs remain prone to hallucinations and factual errors (Zhai, 2025).

Fine-tuning a language model on legal corpora can improve stylistic alignment but does not guarantee up-to-date knowledge and requires costly retraining whenever regulations change. Moreover, fine-tuned models internalize knowledge parametrically, making source attribution and traceability difficult, which is an important limitation in compliance and sensitive contexts. To address these limitations, Lewis et al. (2020) introduced RAG, which combines language models with document retrieval to ground responses in external knowledge sources, thereby improving factual accuracy and transparency. RAG extends LLMs by combining text generation with external information retrieval. Instead of relying only on knowledge learned during training, the system retrieves relevant document fragments from a document database and incorporates them into the prompt used for answer generation. This process grounds responses in verifiable sources, improving factual accuracy, and reducing hallucinations. By separating knowledge retrieval from language modeling, RAG thus enables domain adaptation without requiring model fine-tuning or large annotated datasets (Hindi et al., 2025). These properties make RAG particularly well-suited for evolving legal and regulatory environments where precision, traceability, and adaptability are critical.

Legal QA ranges from simple binary or multiple-choice tasks to long-form explanatory responses and is commonly implemented as a two-stage pipeline that integrates semantic retrieval with LLM-based answer generation (Redelaar et al., 2024).

Building on this paradigm, recent studies have applied RAG-based legal QA across several national contexts. For instance, Matak and Chudziak (2025) develop a system based on the Polish Civil Code, contributing valuable evidence for non-English legal settings. Their work examines how chunking strategies influence retrieval efficiency and downstream performance. However, evaluation relies on an exam-style multiple-choice format in which the model selects among predefined answers, making it unclear whether the setup truly measures retrieval quality. As a result, answer selection may be conflated with genuine retrieval effectiveness.

Wiratunga et al. (2024) introduce a case-based reasoning approach for RAG using an Australian law QA dataset and relies on BERT-based models that are explicitly trained for retrieval and similarity matching. While methodologically sound, it shares a similar limitation with the first work: neither paper evaluates whether the retrieved information is actually useful in a human-in-the-loop setting. In particular, there is no assessment of how retrieval supports a user's learning or reasoning process, with the AI acting as an assistant rather than a standalone answer generator.

Prior work on Thai legal QA has largely focused on statutory domains such as financial law and tax law. These studies construct datasets and benchmarks exclusively from Thai legal documents, without incorporating English or other languages. The resulting QA datasets are verified against authoritative legal references to ensure factual correctness. However, these systems are evaluated primarily through offline benchmarking and automated metrics. They are not deployed or assessed in real-world usage scenarios, and no human users are involved in evaluating system performance in practice. Moreover, the systems are not designed or studied as tools for user learning, such as supporting legal education or practitioner knowledge acquisition, but rather as static benchmarks for model comparison (Akarajaradwong et al., 2025a, 2025b).

In the Indian legal domain, existing work has focused mainly on criminal law and Supreme Court judgments. These studies construct a primary dataset along with a smaller test set to evaluate QA over judicial texts. While QA pairs are provided, the datasets generally lack explicit citation grounding or reference validation, which limits their applicability in learning-oriented or trust-critical settings. Evaluation is conducted without involving human users interacting with the system in realistic legal scenarios. Additionally, these systems are not framed or evaluated as learning tools for users, such as law students or legal professionals, and remain monolingual with no multilingual evaluation (Nigam et al., 2023).

For Chinese civil law, recent efforts introduce QA datasets derived from legal case documents with limited human supervision. In this setting, large language models are used to annotate data under human oversight, but the task formulation is restricted to binary or ternary decision-making (e.g., "yes" versus "no or unknown"). As a result, these systems do not support open-ended answer generation or explanatory responses that would facilitate user learning. Evaluation focuses on annotation quality rather than on human interaction in real legal usage scenarios. Similar to the Thai and Indian datasets, the systems are monolingual, exclude English, and are not evaluated as educational or decision-support tools for end users (Liu et al., 2024).

Text embeddings convert raw text into numerical vector representations that allow machine learning systems to compute semantic similarity and carry out the relevant document retrieval in RAG. Earlier approaches such as TF-IDF rely on sparse frequency-based representations, while static embeddings like GloVe capture global word co-occurrence patterns (Pennington et al., 2014). More recent transformer-based models, including BERT, produce contextual embeddings that encode meaning based on surrounding text, enabling richer semantic understanding (Devlin, 2019; Muchori, Maina, 2025). To compare these embeddings, we use cosine similarity, which measures semantic relatedness by computing the angle between vectors and is widely adopted for retrieval and ranking tasks in embedding-based NLP systems (de Vos et al., 2021).

Taken together, the reviewed literature highlights that many legal QA systems are primarily evaluated using benchmark-style metrics, while comparatively little attention is given to how retrieved information supports practical reasoning and decision-making in applied contexts. In operational domains such as logistics compliance, however, the usefulness of AI systems depends not only on answer accuracy but also on the transparency and traceability of the supporting legal sources.

Accordingly, the architecture adopted in this study emphasizes practical interpretability in addition to technical retrieval performance. Rather than focusing solely on automated QA accuracy, the system is designed to expose the retrieval process and supporting evidence. Through a user-facing interface, practitioners can inspect the source document, page reference, and exact text segment used during answer generation. This design enables users to verify factual accuracy, assess relevance, and consult the broader legal context when necessary. In this way, the proposed RAG framework is positioned as an assistive decision-support tool that complements human interpretation rather than functioning as a fully automated black-box answer generator.

3. Methods

Prior research on legal QA often depends on large, annotated datasets and task-specific fine-tuning. In specialized operational domains such as road logistics, comparable QA datasets are scarce and building them at scale would require extensive manual effort. To address this constraint, we adopt a lightweight strategy based on a general RAG pipeline combined with targeted prompt engineering. The system grounds answers in a curated corpus of Polish and EU road-transport legal documents by retrieving relevant passages at query time and generating citation-linked responses, avoiding the need for training a domain-specific model on thousands of labeled question-answer pair examples.

We evaluate the feasibility of this approach using an offline test set of 50 Polish practitioner-style questions with verified answers and article-level references. Evaluation focuses on (i) retrieval success (whether the system retrieves the correct legal basis), (ii) answer correctness relative to the reference answers, and (iii) citation grounding quality (whether cited passages support the generated answer). This design enables a reproducible assessment of a domain-specific legal QA system in road logistics without relying on large-scale annotated corpora or user studies in the conference version.

3.1. Dataset Construction and Data Preparation

Despite rapid progress in legal QA, there is currently no domain-specific dataset or evaluation framework targeting Polish road transport compliance. Developing such a dataset at scale would require substantial expert involvement to formulate practitioner-style questions, verify legally correct answers, and annotate precise citation spans. This creates a significant practical barrier to deploying AI-based compliance tools in logistics practice.

More broadly, recently developed open-domain question answering (OpenQA) systems typically depend on large-scale annotated datasets to achieve state-of-the-art performance. However, producing these resources is labor-intensive and costly, as it requires expert validation, span-level annotation, and citation grounding. As a result, high-quality legal QA benchmarks are available only for a limited number of languages, primarily English and Chinese (Rybak et al., 2024).

As summarized in Table 1, most widely used legal QA benchmarks focus on general legal domains such as case law, contract review, mergers and acquisitions, privacy policies, or national judicial examinations. These large datasets are predominantly in English or Chinese and are designed for broad legal reasoning tasks rather than sector-specific operational contexts.

Table 1.
Benchmark Legal Question Answering Datasets

Dataset	Legal Domain	Size	Language	Authors
CaseHOLD	U.S. case law (holding identification from citations)	53,000+ multiple-choice questions	English	(Zheng et al., 2021)
COLIEE 2024 - Task 1 and Task 2	Federal Court of Canada case law	5000+	English	COLIEE 2024
CUAD	Contract review / clause extraction	13,000	English	(Hendrycks et al., 2021)
MAUD	Merger Agreement Understanding	over 39,000 examples and over 47,000 total annotations	English	(Wang et al., 2023)
JEC-QA	National Judicial Examination of China	26,365 multiple-choice questions	Chinese	(Zhong et al, 2020)
PolicyQA	privacy practices	25,017 reading comprehension style examples and 714 human-annotated questions	English	(Ahmad et al., 2020)
CJRC	Chinese judicial reading comprehension	50,000 questions with answers	Chinese	(Duan et al., 2019)
PolQA	Criminal & civil court judgments; tax interpretations; administrative decisions	7,000 questions, 87,525 manually labeled evidence passages	Polish	(Rybak et al., 2024)

Source: Own materilas.

Even recent retrieval-focused benchmarks such as LegalBench-RAG (Pipitone, Alami, 2024) evaluate retrieval performance across diverse legal corpora but do not target transport-specific regulations or compliance-oriented practitioner questions. Similarly, the Polish PolQA dataset (Rybak et al., 2024) provides an important contribution for Polish-language QA; however, it covers criminal and civil court judgments rather than operational road-transport regulations.

Importantly, none of these benchmarks are tailored to the domain of road transport compliance, where practitioners require fast, actionable, and citation-grounded answers linked to specific EU and national transport regulations (e.g., AETR, Regulation 561/2006, CMR, ADR). Developing a large-scale, fully annotated QA dataset for this specialized domain in Polish would require substantial expert effort to formulate realistic practitioner-style questions, verify answers, and annotate precise legal references. Given the dispersed and frequently updated nature of transport regulations, maintaining such a dataset would further increase the resource burden.

In order to evaluate our proposed approach, we constructed a domain-specific dataset of 50 Polish legal QA pairs covering core road-transport compliance topics (e.g., driving and rest times, cabotage, carrier liability, dangerous goods, and customs transit).

Table 2.
Overview of the legal Q&A dataset fields with illustrative examples

Question / English	Answer / English	Question / Polish	Answer / Polish	Document	Cite	Page
What are the objectives of the legal regulations in the AETR?	The objective of the regulations included in the AETR is to improve road safety and drivers' working conditions.	Jakie są cele regulacji prawnych w AETR?	Odpowiedź: Celem regulacji ujętych w AETR jest poprawa bezpieczeństwa ruchu drogowego i warunków pracy kierowców.	European Agreement concerning the work of crews of vehicles engaged in international road transport (AETR). Preamble	BEING DESIROUS of promoting the development and improvement of the international transport of passengers and goods by road, CONVINCED OF the need to increase the safety of road traffic, to make regulations governing certain conditions of employment in international road transport in accordance with the principles of the International Labour Organization, and joined to adopt certain measures to ensure the observance of those regulations, HAVE AGREED	Page: No L 95/ 1

Source: Own materilas.

The questions were developed based on a carefully selected set of 14 Polish and EU legal instruments governing road transport operations. The underlying corpus comprises legal materials in both English and Polish and covers key regulatory domains relevant to logistics and transport, including ADR requirements, the CMR Convention, customs procedures under the A.T.A. Carnet, and the TIR Convention.

In total, the corpus contains approximately 1,432,435 tokens across 2,365 pages of legal documentation. The questions were designed in a practitioner-oriented, compliance-focused format to reflect realistic operational scenarios. All documents correspond to currently applicable legislation, ensuring contemporary relevance for legal and logistics decision support.

Table 2 presents a sample entry illustrating the dataset structure. Each record includes (i) the question in Polish with an English translation, (ii) a verified answer, (iii) the governing legal instrument (e.g., Regulation (EC) 561/2006, CMR, ADR), (iv) the relevant article or section, (v) page reference, and (vi) an exact supporting quotation serving as the gold-standard citation. The dataset is grounded directly in official EU conventions, regulations, and Polish

transport law, enabling citation-based retrieval, explainable responses, and human-in-the-loop validation. The dataset will be made publicly available upon acceptance.

3.2. Retrieval-Augmented Generation System Architecture

The corpus was processed through a standardized ingestion pipeline within a RAG architecture (Figure 1). Our approach adopts a practical RAG stack designed for assistive use in real operational settings. We employ Faiss (Douze et al., 2025) as the vector database for fast document retrieval, OpenAI's text-embedding-3-small model to generate text embeddings, and the gpt-4o-mini model as the language model, with document ranking based on cosine similarity. Faiss is an open-source library for efficient similarity search over large collections of dense vectors, enabling fast approximate nearest-neighbor retrieval of relevant documents at scale (Douze et al., 2025).

The legal documents were loaded from the project directory in heterogeneous formats (including PDF, DOCX, TXT, and spreadsheet files) and converted into a unified representation as LangChain Document objects. Documents were segmented using a recursive character-based chunking strategy with a maximum chunk length of 800 characters and a 10% overlap (80 characters) to preserve semantic continuity across chunk boundaries. Although Figure 1 illustrates the retrieval pipeline using PDF documents for simplicity, the actual corpus included PDF, DOCX, TXT, and spreadsheet files that were converted into a unified document representation prior to indexing.

Each chunk was assigned a stable identifier derived from document name, page number, and chunk index, enabling deduplication and incremental index updates. This process yielded approximately 8,000 text chunks across the corpus. Each chunk was embedded using OpenAI's text-embedding-3-small model (OpenAI, 2024a), producing 1536-dimensional dense vector representations. Embeddings were indexed in a Faiss vector store (IndexFlatL2) configured for exact nearest-neighbor search. Retrieval was conducted using cosine similarity, with the top-k most similar chunks returned per query ($k = 5$ in reported experiments).

While the system also supports alternative retrieval configurations, such as similarity score thresholding (threshold = 0.8) and maximum marginal relevance, these were not employed unless explicitly stated. The retrieved passages were supplied to the gpt-4o-mini language model (OpenAI, 2024b) for response generation, ensuring outputs were grounded in semantically relevant source material.

This design emphasizes deterministic retrieval behavior, reproducible indexing across heterogeneous legal sources, and robust semantic matching suitable for real-world regulatory assistance workflows.

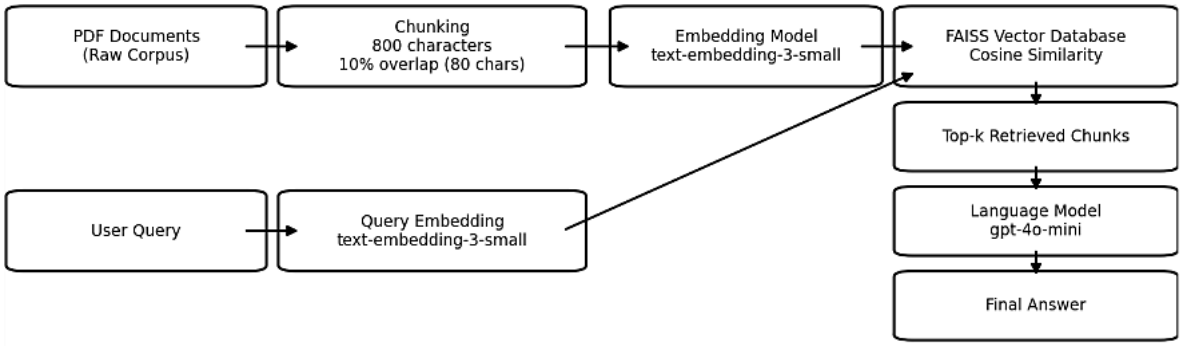

Figure 1. Proposed RAG-Based Legal Question Answering Architecture.
Source: Own materilas.

3.3. Evaluation Framework

Figure 2 illustrates the user interface of our proposed RAG system in its Polish-language configuration. The interface is designed to support transparent and interpretable legal information retrieval, with particular emphasis on document traceability and evidence-grounded response generation. Rather than functioning as a black-box QA system, the interface enables users to observe how retrieved legal sources contribute to the final response, thereby supporting verification and informed decision-making.

The interface is organized into three main functional areas. The left sidebar, labelled in the RAG Menu, serves as the configuration panel through which users can control both retrieval and generation parameters. Within this panel, practitioners can select the retrieval strategy (e.g., similarity-based search), adjust the number of retrieved document chunks (Top-k), choose the embedding model used for semantic indexing, and specify the language model responsible for answer generation. Additional controls allow management of the document database and optional chat history functionality. These configurable parameters enable users to adjust retrieval of sensitivity and model behavior, improving controllability, and facilitating reproducible experimentation across different query settings.

The central panel presents the generated response produced by the language model. Answers are generated conditionally on the retrieved document fragments and displayed in Polish, reflecting the system's intended use in operational legal contexts. This area functions as the primary interaction space, where users submit queries and receive synthesized legal explanations grounded in retrieved regulatory content.

The right sidebar, referred to as the Context Menu, provides the transparency layer of the system and plays a central role in interpretability. It displays the source document from which supporting evidence was retrieved, including the document title, the exact page location, and a rendered preview of the original legislative PDF. The specific text passage used during generation is highlighted within the document view, allowing users to directly verify the legal basis of the response. By exposing both retrieval context and supporting evidence, the interface enables traceable reasoning and supports trust in AI-assisted legal information retrieval.

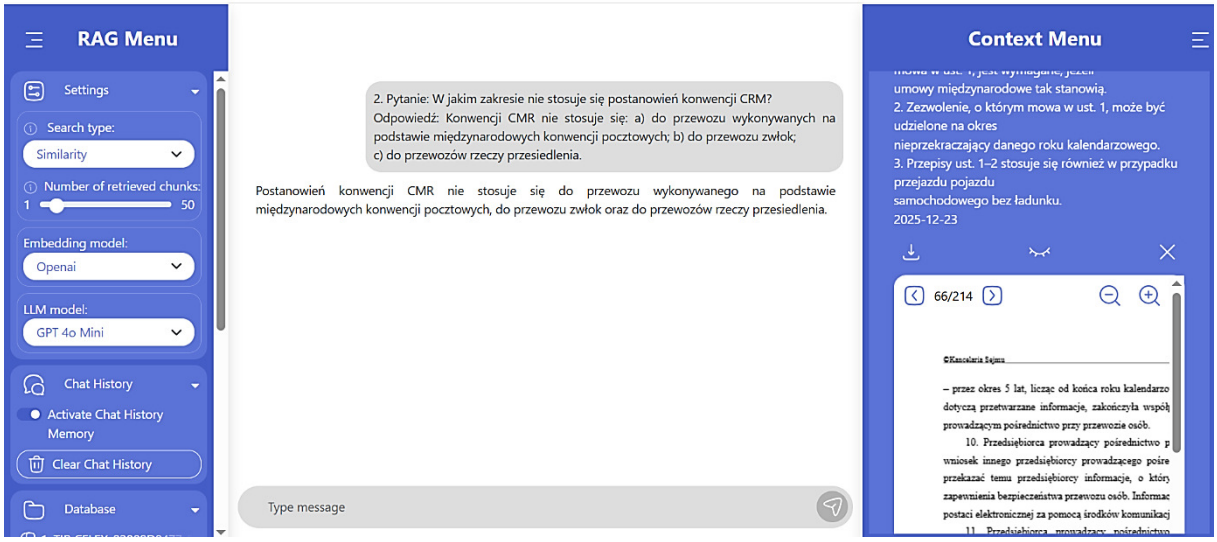

Figure 2. RAG User Interface for Legal Answer Generation and Document Traceability.
Source: Own materilas.

4. Results

This section presents the evaluation results of the proposed RAG-based legal question-answering system. Performance is reported for both one-shot and interactive settings and is assessed using answer correctness, document retrieval accuracy, page-level localization, and citation grounding. The results are presented separately for English and Polish questions and are summarized through quantitative performance metrics.

4.1. Evaluation Design

System performance was evaluated through a structured manual assessment designed to capture different stages of RAG, including answer correctness, document retrieval, and citation grounding. Each system response was annotated using a three-level category scheme. The category “0” indicates that the generated answer or retrieved legal source was incorrect or irrelevant to the query.

The category “1” denotes a correct result obtained directly from the original query without any modification. The category “2” represents cases in which a correct answer or supporting legal evidence was obtained only after minor prompt refinement, such as clarifying jurisdictional scope or explicitly referencing a regulation. This distinction enables the evaluation to separate fully automatic system performance from results achievable through realistic user interaction, reflecting the intended assistive use of the RAG system.

4.2. Performance Analysis

To assess system behavior under both fully automatic and interactive settings, two complementary experiments were conducted. Experiment 1 evaluates one-shot RAG performance, in which queries were submitted without any prompt modification or iterative interaction on the whole dataset. The results are summarized in Table 3. The "Cases" column reports the number of evaluated QA instances for each dataset condition.

The Answer metric measures the proportion of responses categorized as "1", representing correct answers produced directly from the original query. Retrieval performance is evaluated separately using the "Document" metric, which measures whether the legally relevant source document was retrieved, and the "Page" metric, which assesses whether the relevant evidence was localized at the correct page level. Finally, "Grounded" represents the strictest evaluation criterion, counting only cases in which the answer was correct and supported by both the correct document and page, indicating fully verifiable responses.

Table 3.
One-shot RAG performance (without prompt refinement)

Condition	Cases	Answer	Document	Page	Grounded
Combined	99	59%	58%	31.3%	26.3%
English QA	45	69%	78%	42.2%	33.3%
Polish QA	44	61.4%	37%	25%	25%

Source: Own materilas.

Experiment 2 investigates interactive use of the system, acknowledging that RAG workflows are inherently iterative and users may refine prompts to improve results. In this experiment, conducted on a subset comprising approximately half of the dataset, users were allowed to modify the original query when the initial response was incorrect or insufficient. The outcomes of this process are presented in Table 4, which distinguishes between answers obtained directly (correct without refinement) and those achieved only after prompt refinement (correct after refinement), alongside remaining incorrect cases.

Prompt refinement followed a procedure in which the evaluator was allowed to clarify the original query without altering its substantive meaning. Refinements typically involved adding explicit references to relevant legal instruments (e.g., "According to Regulation (EC) No 561/2006"), specifying jurisdictional context (e.g., EU regulation or Polish law), or encouraging retrieval from additional language sources when the legal corpus contained multilingual documents. These refinements were intended to mimic realistic user interaction, where practitioners may reformulate queries to provide clearer regulatory context.

The Total values reported in Table 4 are calculated by combining results obtained without prompt refinement (category= "1") and those achieved after prompt refinement (category= "2"). Thus, the Total metric captures all cases in which a correct answer was ultimately obtained, either directly from the original query or following minimal query reformulation.

This measure provides an estimate of practical system usability in an interactive decision-support setting. The reported percentages are computed by dividing the sum of these correct outcomes (categories “1” & “2”) by the total number of evaluated cases under each condition, including incorrect responses (category= “0”). The Total row therefore reflects overall system performance after interaction, enabling a direct comparison with the one-shot baseline results presented in Table 3.

Together, these experiments allow separate analysis of (i) baseline automatic performance and (ii) performance achievable through realistic human-in-the-loop interaction. This evaluation design provides a comprehensive assessment of generation accuracy, retrieval effectiveness, and evidential grounding, while also demonstrating the practical benefits of iterative query refinement in legal QA scenarios.

Table 4.
Performance with human-in-the-loop interaction (with prompt refinement)

Condition		Answer	Document	Page	Grounded
COMBINED	Incorrect	9	19	28	-
	Correct without refinement	32	26	16	-
	Correct after refinement	8	4	5	-
	Total	82%	61.2%	43%	41%
ENGLISH QA	Incorrect	2	3	11	-
	Correct without refinement	18	19	10	-
	Correct after refinement	5	3	4	-
	Total	92%	88%	56%	52%
POLISH QA	Incorrect	7	16	17	-
	Correct without refinement	14	7	6	-
	Correct after refinement	3	1	1	-
	Total	71%	33.3%	29.2%	29.2%

Source: Own materilas.

The comparison between Tables 3 and 4 demonstrates that allowing minimal prompt refinement substantially improves overall system effectiveness across all evaluation dimensions. Under one-shot conditions (Table 3), the system achieved moderate answer accuracy (59% for the combined dataset), with comparable document-level retrieval performance (58%). In contrast, page-level localization (31.3%) and fully grounded responses (26.3%) were substantially lower. This pattern suggests that one-shot prompting may not always provide sufficient guidance for the RAG system to identify and incorporate the most relevant supporting passages. As a result, answers may be generated without clearly grounded evidence, indicating that additional clarification or prompt refinement may be required to obtain fully supported responses.

When interactive refinement was introduced (Table 4), performance increased markedly. Combining answers obtained directly with those achieved after prompt refinement raised answer accuracy to 82% in the combined dataset, alongside improvements in document retrieval (61.2%), page identification (43%), and grounded responses (41%). These results indicate that many initial failures were not caused by missing knowledge but by ambiguity in

query formulation, which could often be resolved through minor clarification of jurisdictional scope or regulatory references. The findings therefore highlight iterative interaction as an inherent component of practical RAG deployment rather than a secondary correction mechanism.

Performance differences between language conditions further support this interpretation. English-language queries consistently achieved higher scores, even when underlying legal materials were available only in Polish. This pattern likely reflects stronger English representation in current embedding and language models rather than limitations of the retrieval framework itself. Nevertheless, meaningful performance was maintained across both datasets, suggesting that general-purpose RAG architectures can operate within multilingual regulatory environments typical of European road logistics without domain-specific fine-tuning.

Qualitative analysis revealed that retrieval behavior was highly sensitive to prompt specificity and linguistic cues. For example, when the question was phrased generically as: "What is the break time after 4.5 hours of driving?", the system initially retrieved a legally valid but contextually different provision (30 minutes) grounded in broader Polish working-time regulations. However, when the question explicitly referenced "According to Regulation (EC) No 561/2006", the system correctly retrieved Article 7 of the Regulation and generated the expected answer (45 minutes). This observation illustrates how minor variations in wording and jurisdictional cues can substantially influence retrieval behavior. Importantly, such ambiguity reflects real business practice, where legal and operational questions are often formulated imprecisely even by domain experts operating in their native language, reinforcing the importance of prompt design in assistive legal QA systems.

Similarly, adding the phrase "in Polish law" altered document retrieval behavior, prioritizing national legislation over EU regulations. Increasing the number of retrieved documents (k-value) further influenced citation grounding. These findings indicate that general-purpose RAG systems are highly sensitive to linguistic specification and jurisdictional cues. Rather than constituting system errors, such variations reflect the layered structure of transport legislation and the interaction between the EU and national law. From a practical perspective, this suggests that prompt design plays a critical role in achieving accurate and regulation-specific legal QA.

In several instances, the LLM successfully retrieved the correct document and relevant section but nevertheless failed to extract and report the precise answer. For example, in response to the question, *How much can the liability of the ATA Carnet guarantor exceed customs duties and import taxes?* The expected answer is: According to the provisions of the ATA Convention, it cannot exceed 10%.

However, the model generated the following response: "The guaranteeing association shall not be required to pay a sum greater than the total amount of the import duties and taxes, together with any applicable interest". While the correct source passage, "The liability of the guaranteeing association cannot exceed the amount of customs duties and import taxes by more

than 10%", was correctly retrieved and cited in the context window, the model failed to report the critical numerical qualifier (10%) in its final answer. This example illustrates a failure at the answer extraction or synthesis stage rather than at retrieval, where the relevant evidence was available but not accurately incorporated into the generated response.

Overall, the results suggest that lightweight, general-purpose RAG systems can provide practically useful assistance for regulatory QA when used interactively. Performance gains observed under prompt refinement emphasize that legal AI systems should be evaluated not only as static models but as collaborative decision-support tools in which iterative clarification plays a central operational role. Future improvements are therefore likely to depend on enhanced multilingual retrieval, improved prompt guidance, and stronger evidence-aware answer generation mechanisms.

5. Discussion

Regulation is often understood primarily as a mechanism that restricts behavior; however, it also plays an enabling role by creating structured and predictable conditions that allow complex systems such as international transport to operate effectively. By addressing market failures and establishing shared rules, regulatory frameworks support coordination, safety, and accountability across actors.

Consequently, understanding regulation becomes an operational necessity in logistics practice, where daily decisions depend on interpreting multilayered legal requirements (Baldwin et al., 2011). The empirical findings of this study highlight that this challenge is increasingly not only legal but informational: the rapid growth of available data and the expanding complexity of regulatory frameworks make effective legal understanding progressively more difficult for practitioners. Even experienced professionals struggle to locate and interpret relevant provisions across large and continuously evolving bodies of law, while information obtained from general online sources often varies in reliability. Although large language models enable natural-language access to legal information, their tendency to produce confident but incorrect responses limits their applicability in high-stakes regulatory contexts. These limitations have motivated the adoption of RAG, which grounds AI responses in retrieved legal sources to improve reliability and reduce hallucinations (Li, 2024).

Against this background, the results demonstrate that regulatory QA can be supported through a deliberately lightweight and operationally oriented RAG architecture. Compared with recent legal RAG-based QA systems, which frequently introduce hybrid pipelines, knowledge graphs, or multi-model reasoning mechanisms, the proposed approach prioritizes transparency, reproducibility, and deployability. Hybrid legal QA agents, for example, integrate RAG with model ensembling and human-in-the-loop updating to improve robustness in judicial

environments (Xi et al., 2025), while survey evidence shows that advanced legal RAG systems increasingly rely on iterative retrieval, knowledge graph augmentation, or fine-tuned generators to enhance reasoning performance (Hindi et al., 2025).

In contrast, our framework employs a single-stage retrieval pipeline using dense embeddings and a general-purpose language model. Rather than representing an optimized or fully tailored legal QA architecture, this configuration serves as a lightweight baseline intended to evaluate whether retrieval-grounded generation can already provide meaningful regulatory assistance in an operational setting. The results indicate that even without architectural extensions such as iterative retrieval, model fine-tuning, or knowledge-graph integration, grounded answers can be produced with reasonable reliability. This suggests that practical compliance-oriented support may be achievable using relatively modest system configurations, while more complex architectures remain a promising direction for future improvement, particularly in environments where higher precision or deeper legal reasoning is required. As the present study was not designed as a controlled multilingual retrieval experiment, the observed differences between English and Polish queries may reflect a combination of embedding-model characteristics, corpus language composition, translation effects, and query formulation strategies.

Moreover, the numerical extraction risk Carnet example demonstrates that retrieval-grounded systems may still generate incorrect responses when critical numerical information is omitted during answer synthesis. In compliance-sensitive environments, such omissions may lead to incorrect operational decisions despite successful retrieval of the relevant legal source. Therefore, future work should investigate mechanisms for improving numerical consistency and evidence-aware answer generation.

From a research perspective, this study contributes a domain-specific Polish legal QA dataset, an expert-validated RAG framework, and empirical insights into how AI systems can complement human expertise in regulatory decision support. The results indicate that general-purpose RAG systems can support transport legal QA without domain-specific fine-tuning, achieving meaningful assisted accuracy across multilingual queries. Performance was consistently higher when questions were formulated in English, even when source documents were available in Polish. Rather than representing a system failure, this pattern reflects the stronger English representation within current embedding and language models and reveals how multilingual semantic spaces and jurisdictional cues influence retrieval behavior. In practice, this finding mirrors the layered interaction between EU-level and national transport legislation, where linguistic formulation implicitly guides regulatory interpretation. Importantly, the system maintained consistent performance across languages, demonstrating that general RAG architectures can operate within multilingual regulatory environments typical of European road logistics.

From an operational standpoint, these results are significant because logistics practitioners rarely require fully formal legal reasoning; instead, they need rapid orientation toward applicable regulations supported by traceable sources. The observed variation between Polish and English queries therefore illustrates not merely technical limitations but the structural complexity of regulatory environments and the importance of prompt formulation in compliance-oriented legal QA. Taken together, the findings suggest that practical AI-assisted compliance support may be achievable without costly domain adaptation, while future improvements are likely to arise from multilingual retrieval optimization and human-in-the-loop interaction design. By demonstrating that grounded legal assistance can be achieved using general-purpose models and modest data resources, this study highlights a pathway toward scalable, transparent, and operationally usable AI systems for regulatory decision support.

6. Conclusion

This study demonstrates the feasibility of applying RAG system to operational legal QA in road logistics, an area where practitioners must navigate complex and continuously evolving regulatory frameworks. Using a lightweight architecture and a curated practitioner-oriented dataset, the proposed system produced citation-linked answers that supported regulation discovery and interpretation without requiring large-annotated corpora or domain-specific model fine-tuning. The findings suggest that effective regulatory assistance can be achieved through grounded retrieval rather than increasingly complex model adaptation, although precise citation localization remains a key technical challenge.

By introducing a transport-specific legal QA dataset and empirically analyzing multilingual and prompt-sensitivity effects, the study provides initial evidence that AI-assisted regulation search can help bridge the gap between complex legal frameworks and everyday logistics decision-making. These results highlight the potential of transparent, retrieval-based AI systems as practical compliance support tools and establish a foundation for future human-in-the-loop evaluation and workflow-integrated regulatory assistance systems.

This study has several limitations. The evaluation was conducted on a pilot dataset of 50 questions and focused on a specific regulatory domain and jurisdiction. Furthermore, the system was evaluated in an offline setting rather than through real-world user studies. Despite these limitations, the findings provide evidence that retrieval-grounded AI can support regulatory decision-making through transparent, citation-linked responses. The study contributes new knowledge regarding the role of prompt specificity, multilingual retrieval behavior, and human-in-the-loop interaction in legal QA systems. These insights can inform the design of future compliance-support tools and provide a foundation for larger-scale evaluations in logistics and other regulated industries.

7. Future directions

Prior literature consistently highlights a tension between regulatory demands and operational realities in road logistics. Legal and transport regulations are formal, mandatory, and directly influence operational performance, yet their volume, dispersion, and technical language make systematic interpretation difficult in fast-paced settings. As a result, practitioners frequently rely on tacit or experience-based knowledge, which may lead to inconsistent compliance and increased operational risk. Although AI applications in logistics have demonstrated benefits for decision support and process optimization, existing legal QA and retrieval systems remain largely detached from real-world logistics practice and are rarely evaluated in operational environments with domain experts or end users. Consequently, there is still limited empirical evidence regarding how such systems perform in everyday compliance decision-making or how they are perceived by logistics professionals.

Future research should therefore move beyond technical benchmarking and investigate AI-assisted regulation-search tools as socio-technical systems embedded in actual workflows. In particular, studies should incorporate human-in-the-loop and field-based evaluations to examine how practitioners interpret, trust, and act upon AI-generated recommendations. Technology acceptance frameworks provide a suitable theoretical foundation for this line of inquiry. The Technology Acceptance Model explains adoption through perceived usefulness and perceived ease of use (Davis, 1989), while the Unified Theory of Acceptance and Use of Technology extend this perspective by incorporating social and organizational influences (Venkatesh et al., 2003).

These models have been widely applied across logistics and supply chain contexts, including the adoption of digital technologies (Li et al., 2025), IoT-based systems (Katias, 2025), blockchain platforms (Sharma, 2023; Wong et al., 2024), and mobile logistics applications (Persada et al., 2023). Empirical findings consistently show that perceived usefulness, ease of use, and facilitating conditions strongly determine system uptake. For example, Castiblanco et al. (2026) demonstrate that TAM effectively explains logistics workers' acceptance of monitoring technologies. However, only a limited number of studies combine AI-driven decision-support tools with structured user-acceptance evaluation, such as the TAM/UTAUT-based assessment reported by Adayilo et al. (2026). Importantly, to date, no studies have applied such acceptance frameworks to RAG systems or examined their adoption in the specific context of road transport regulation and compliance.

Accordingly, future work should extend the present research by conducting longitudinal user studies and expert evaluations of AI-assisted legal QA systems in road logistics, assessing not only technical accuracy but also usability, trust, learning effects, and integration into daily operational practices. Such investigations would provide stronger evidence of practical value and help ensure that regulation-search technologies effectively bridge the gap between complex

legal requirements and real-world logistics decision-making.

Regarding the RAG system, a promising direction for future research is the integration of structured metadata into the RAG pipeline to improve answer precision, particularly for numerically sensitive regulatory queries. During ingestion, chunks could be enriched with explicit metadata fields capturing quantitative elements such as percentages and time limits. Such structured annotations would enable metadata-aware retrieval, filtering, or re-ranking mechanisms that prioritize passages containing explicit quantitative constraints. This approach may substantially reduce the risk that critical numerical qualifiers are overlooked during answer synthesis, thereby improving factual accuracy and reliability in legal and regulatory assistance systems.

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SENIORS' SENSE OF DIGITAL SECURITY AND THEIR ACTIVITY IN USING INTERNET SERVICES

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Purpose: The purpose of the article is to analyse the relationship between the awareness and sense of digital security of seniors and their activity in using Internet services in the context of information security management.
Design/methodology/approach: The study used quantitative analysis of data collected using the PAPI technique on a sample of 220 people aged 60+. The research tool was a questionnaire containing questions about digital literacy, frequency of internet use, sense of security and experiences of threats.
Findings: The results indicate that seniors are active Internet users, but their participation in the digital environment is diverse. Higher self-assessment of digital competence is associated with more frequent internet use, while a lower sense of security and fear of fraud limit one's online activity. The respondents also report high awareness of the most common online threats.
Research limitations/implications: The study included 220 seniors from Poland, which limits the possibility of full generalization of the results. The sample was diverse but not fully representative, especially in terms of regional structure. Further research should include a larger and more balanced sample and consider variations in digital competences by age, place of residence, and professional experience.
Practical implications: The results can support the design of educational activities aimed at seniors and the creation of simpler and safer digital solutions. They also have implications for public institutions, banks, and online service providers, which should consider the needs of older users.
Originality/value: This article combines the perspectives of digital literacy, sense of security, and information security management, focusing on seniors as a group that is particularly vulnerable to online threats.
Keywords: seniors; digital competence/skills/literacy; information security; Internet; digital exclusion.
Category of the paper: Research paper.

1. Introduction

Poland, like other European Union member states, has been facing a growing demographic challenge for many years, which is the systematic increase in the percentage of older people in the structure of society. This phenomenon generates significant consequences for the functioning of the social system, the labour market, health care and public policy, and also places new requirements on the adaptation processes related to the ongoing digitalization (Hargittai, Dobransky, 2017; van Deursen, Helsper, 2015). In this context, the issue of digital integration of people over 60, understood as the possibility of their full and safe participation in the information and service environment of modern society, is of particular importance. This problem was already noticed at the strategic level, which was reflected in the inclusion of the activation of older people in the Lisbon Strategy adopted by the European Council in 2000. This document emphasized, among other things, the need to support the employment of older people through training and competence-building activities, which was to help them stay longer in the labour market.

The ongoing digitalization of social and economic life has led to the fact that using the Internet is no longer just an additional option but has become a condition for effective functioning in many areas of everyday life (Park, Nam, Cha, 2021; Xie, 2025). This applies to contact with public institutions, the implementation of financial operations, access to information, and maintaining social relations. For older people, this means not only mastering basic technical skills but also developing competences that allow for critical evaluation of content, recognition of risks, and also conscious and responsible use of digital services (Maciąg, 2021; Olphert, Damodaran, 2013). At the same time, the intensive development of communication technologies contributes to the increase in the number of threats in cyberspace, such as phishing, identity theft, online fraud and personal data theft, which further complicates the situation of users with a lower level of digital competences (Crossler, Belanger, 2014; Whitman, Mattord, 2021).

Seniors are a group that is particularly vulnerable to digital exclusion, which should be understood not only as a lack of access to technologies, but also as a limitation of their effective, safe and autonomous use (Hargittai, Dobransky, 2017; van Deursen, Helsper, 2015). This exclusion is multidimensional and may result from hardware, economic, cognitive, psychological and social barriers. In practice, this means that some older people, despite the formal availability of the Internet and electronic services, are not able to fully use them due to insufficient competences, fear of making a mistake, low level of trust in technology or negative experiences related to their use (Olphert, Damodaran, 2013; van Dijk, 2020). Such restrictions lead to enhancement of social inequalities because they exclude seniors from important areas of public life. Importantly, a lack of competence in information security may reinforce concerns about using the Internet and thus lead to abandonment of digital services even when they are

potentially useful. As a result, both the actual level of knowledge about threats and the subjective sense of digital security may significantly influence the scope of seniors' activity in the online environment (Bulgurcu et al., 2010; Hargittai, Dobransky, 2017).

The purpose of the article is to analyse the relationship between the awareness and sense of digital security of seniors and their activity in using Internet services in the context of information security management.

2. Literature review

2.1. Information security management

Services such as online banking, e-government, medical platforms and instant messengers provide convenience and increase access to information and services, but at the same time require an appropriate level of digital competences and the ability to identify threats (Whitman, Mattord, 2021). In the case of older people, these skills may be limited by less technological experience, lower self-confidence in using digital tools and greater susceptibility to manipulation (Maciąg, 2021).

Information security management should therefore not be understood solely as a set of technical data protection measures, but as a comprehensive process that also covers the end user, their knowledge, behaviour and level of threat awareness (Crossler, Belanger, 2014; Siponen, Oinas-Kukkonen, 2007). The effectiveness of security systems depends not only on the infrastructure security measures used, but also on organizational and human factors, including the ability to recognize social engineering attacks, the use of secure passwords, and the careful use of electronic messages and links sent online (Siponen, Oinas-Kukkonen, 2007). In the case of seniors, the importance of these elements is particularly high, as cybercriminals often take advantage of the limited vigilance of this group by impersonating public institutions, banks or family members.

Therefore, the literature emphasizes the need to develop educational activities aimed at seniors, which should be adapted to their cognitive and practical needs (Olphert, Damodaran, 2013). Effective support programs cannot be limited to providing theoretical knowledge, but should include practical exercises, simple language of communication and the possibility of individual support in problem situations (Mick, Fournier, 1998; Olphert, Damodaran, 2013). Research shows that a digital safety training increases one's awareness of threats, strengthens the sense of empowerment and promotes more conscious use of the Internet by older people (Mick, Fournier, 1998; Olphert, Damodaran, 2013). In this way, educational activities become one of the key elements of information security management for this group of users.

From an organizational perspective, this means that public institutions, financial entities and digital service providers should design solutions that take into account the needs of seniors. This applies to both IT system interfaces and security procedures, which should be clear, intuitive and possible to use independently (Bulgurcu et al., 2010). The literature indicates that excessive complexity of security procedures may paradoxically reduce their effectiveness, because users – especially older ones – refrain from using them or perform them incompletely (Bulgurcu et al., 2010). Therefore, effective information security management should combine technical protection with ease of use and educational support.

Including seniors in the analysis of information security management also allows for a better understanding of the social consequences of digitalization. Older people who do not feel safe in the online environment are more likely to limit the use of e-services, which leads to an enhanced digital exclusion and a reduction in their participation in social life. Therefore, information security should be considered not only as a matter of data protection, but also as a condition for digital inclusiveness, enabling all social groups to fully and safely participate in the information society (Helsper, 2012; van Dijk, 2020).

2.2. Digital literacy of seniors

With the increasing digitalization of social, economic and administrative life, the ability to use information and communication technologies has become an essential element of everyday functioning (van Dijk, 2020; European Commission, 2022).

Digital literacy can be understood as a set of knowledge, skills and attitudes that enable effective, critical, safe and responsible use of digital technologies. These include not only the basic operation of devices and applications, but also the ability to search, select and evaluate information, communicate via digital tools, solve technical problems and protect personal data and privacy in the online environment (European Commission, 2022).

In the case of seniors, digital competences play a particularly important compensatory and integrative role (van Dijk, 2020). On the one hand, they help eliminate barriers related to limited mobility, lower availability of stationary services and difficulties in direct social contact. On the other hand, they enable the use of an increasing number of services transferred to the digital space. Research shows that the level of digital skills affects the quality of life of older people because it strengthens their independence, facilitates access to health and social information and supports maintaining interpersonal relationships (Xie, 2025). In this sense, digital competences are not only a technical tool, but also a social and psychological resource.

However, the level of digital literacy of seniors varies and depends on many factors, such as education, financial situation, place of residence, health condition, previous professional experience and social environment (Hargittai, Dobransky, 2017; van Deursen, Helsper, 2015). Older people living in large cities, with higher education or previous professional experience related to technology, often demonstrate higher levels of digital literacy than seniors from rural areas or those who have not used computer tools before

(van Deursen, Helsper, 2015; Hargittai, Dobransky, 2017). In Polish conditions, the level of digital competences of older people still remains diverse, and some of them have difficulties in using digital devices and services independently, which increases the risk of information and social exclusion (UKSW, 2023).

In practice, many seniors have only basic digital skills, limited to using a mobile phone, browsing websites or sending messages. More advanced activities, such as using public e-services, online shopping, e-banking, configuring privacy settings or recognizing digital threats, may pose a significant challenge for them (van Deursen, Helsper, 2015). As a result, some older people use the Internet selectively and cautiously, focusing only on the simplest functions that they consider safe and understandable (Maciąg, 2021; Olphert, Damodaran, 2013).

The development of digital skills among seniors faces a number of barriers. One of the most frequently mentioned one is the fear of making a mistake and the negative consequences of using technology (Hargittai, Dobransky, 2017; van Deursen, Helsper, 2015). Older people may be afraid of data loss, financial fraud, installing malware or making irreversible changes to their device. Another obstacle is the low self-esteem of one's own competences, which may lead to giving up on trying to learn new solutions on one's own (Hargittai, Dobransky, 2017). The literature also highlights the importance of complexity of digital interfaces and procedures, which are often not designed with the needs of older users in mind. Excessive complexity of systems may reduce the effectiveness of their use and reinforce the feeling of exclusion (van Deursen, Helsper, 2015; Hargittai, Dobransky, 2017).

An important dimension of seniors' digital literacy is also the safety of using the Internet. The ability to recognize reliable sources, assess the authenticity of messages, use strong passwords, protect personal data and identify phishing attempts is now one of the basic elements of digital independence (Bulgurcu et al., 2010). Lack of competence in this area may lead to particular vulnerability to manipulation and online fraud. As the literature on user behaviour indicates, effective use of technology requires not only technical knowledge, but also awareness of risks and a willingness to apply the principles of safe use (Bulgurcu et al., 2010). In the case of seniors, this is particularly important because they are often the targets of attacks using social engineering, fake news and attempts to impersonate public or financial institutions (ENISA, 2025).

2.3. Threats in the digital environment

The development of information and communication technologies has brought numerous benefits, but at the same time it has created new areas of risk. The digital environment, understood as a set of services, devices, platforms and communication channels based on Internet technologies, has become an area of intense user activity and, at the same time, a field of action for cybercriminals (ENISA, 2024; Whitman, Mattord, 2021). The literature emphasizes that digital threats are not limited to technical problems, but also include social,

psychological and organizational aspects, affecting users' trust, behaviour and level of participation in online life (Whitman, Mattord, 2021).

Modern threats in the digital environment are multidimensional and dynamic. They include, among other things, phishing, identity theft, financial fraud, malware, fake websites, social engineering manipulation, data leaks, and various types of attacks on user accounts (NASK, 2024; ENISA, 2024). From the perspective of information security, it is particularly important that many of these threats exploit not so much technical loopholes as human weaknesses, such as haste, lack of vigilance, trust in messages or difficulty in recognizing inauthentic content. Therefore, effective protection against digital threats requires not only technical security measures, but also appropriately developed user competences and risk awareness (Bulgurcu et al., 2010; Siponen, Oinas-Kukkonen, 2007).

Financial fraud is also a significant threat area. With the widespread use of online and mobile banking, cybercriminals are increasingly focusing on gaining access to bank accounts, payment card details, and transfer authorizations (PAP, 2024; NASK, 2024). Seniors who use online payments may be exposed to fake banking websites, dishonest online stores, impersonations of bank consultants or attempts to obtain authorization codes. According to expert reports, older people are a frequent target of this type of activities, and the scale of financial fraud attempts against this group remains significant (PAP, 2024; Bank Pocztowy, 2026).

The risks associated with privacy violations and personal data leakage cannot be ignored either. In the digital environment, users leave behind numerous information traces that can be collected, analysed and used in a way that is against their will. For seniors, who are not always aware of the scale of data processing, this is a serious challenge. Lack of knowledge about privacy settings, cookie policies, or online tracking mechanisms can lead to unintentional sharing of personal information. From a data protection perspective, this issue is particularly important because privacy violations can be the starting point for further criminal activities, including identity theft, harassment or advertising manipulation (Whitman, Mattord, 2021).

Preventive and educational efforts are crucial. Research and institutional studies indicate that increased digital literacy among seniors translates into greater resistance to fraud and more conscious use of online services (PAP, 2024; NASK, 2024). This includes such abilities as recognizing suspicious messages, using strong passwords, using multi-factor authentication, checking website addresses, and being wary of unexpected requests for data or money (NASK, 2024; ENISA, 2024).

3. Research methodology

The purpose of the study was to identify the relationship between the level of awareness and sense of digital security of seniors and their activity in using Internet services, taking into account issues related to information security management. In order to achieve the research objective, two hypotheses were formulated:

H1. A higher level of digital competence among seniors promotes more frequent use of the Internet and electronic services.

H2. The level of awareness of threats and the sense of digital security are significantly related to the activity of seniors in using internet services.

The study was carried out as part of the project "Together for the safety of seniors" using the PAPI technique, i.e. a direct questionnaire interview conducted using a paper form. The questionnaire consisted of 13 main questions divided into four thematic sections covering demographic characteristics, digital literacy, sense of digital security and the use of electronic services. The first part included questions concerning gender, education, place of residence and source of income. The second section focused on the respondents' level of digital literacy and frequency of Internet use, while the third part concerned perceived online threats, sense of digital security and experiences related to fraud attempts in the digital environment. The final section referred to the use of selected electronic services, including online banking, communication platforms and public e-services. Most of the questions were closed-ended and based on ordinal response scales allowing respondents to assess the frequency of Internet use, level of digital competences and perceived online security. Several questions allowed respondents to indicate more than one answer, especially in the part concerning the identification of online threats and previous experiences with fraud attempts. The research tool also allowed us to identify respondents' attitudes towards cyber threats.

The research group consisted of elderly people over 60 years of age who lived in Poland. A total of 220 respondents participated in the study. The collected data was analysed quantitatively, and the results were converted to percentages, which were then rounded to one decimal place.

The structure of the research sample was diversified in terms of sociodemographic characteristics, which allows for a multidimensional characterization of the studied population.

Women clearly predominated among the respondents, constituting 72.2% of all subjects, while the percentage of men was 27.8%. In terms of education level, the largest category were people with secondary education, who accounted for 49% of the sample. The subsequent places were occupied by people with higher and vocational education, while people with primary education constituted only 0.9% of the respondents. In terms of place of residence, respondents living in urban communes (municipalities) were the dominant group, constituting 83.6% of the sample. The share of residents of rural communes and urban-rural communes was much

smaller. The analysis of the source of income shows that more than half of the respondents were retirees and pensioners (53.4%), and the next large group were salaried employees (36.1%). Other sources of income, such as own business, contract of mandate, occasional work, agriculture, unemployment or other forms of income, were marginal. This means that the sample was largely dominated by people outside the full, active labour market. The structure of the studied sample is presented in detail in Table 1.

Table 1.
Characteristics of the study sample

Variable	Category	% of responses
Gender	Male	27.8
	Female	72.2
Education	Primary	0.9
	Vocational	14.1
	Secondary	49
	Higher	35.9
Place of residence	Urban commune	83.6
	Urban-rural commune	6.1
	Rural commune	10.3
Source of income	Salaried employment	36.1
	Agriculture	0.5
	Own business	3.7
	Contract of mandate	3.2
	Retiree/pensioner	53.4
	Occasional work	0.9
	Unemployed	1.4
	Other	0.9

Source: Own study.

The structure of the research sample indicates that the study covered mainly socially active and relatively well-educated people, which may contribute to a higher level of orientation in the digital environment. At the same time, the significant share of retirees and pensioners confirms that the sample largely reflects the senior population to which the analysed results refer. This profile of respondents provides an important background for further analysis of their digital competences, Internet use and perceived online security.

4. Research results

4.1. Digital literacy and Internet use

The first part of the results analysis focused on the digital competences of the surveyed seniors and the frequency of their Internet use. The comparison of answers to questions about self-assessment of Internet skills and the intensity of Internet use allows us to determine the general level of digital engagement of respondents and provides a starting point for further considerations regarding their online activity.

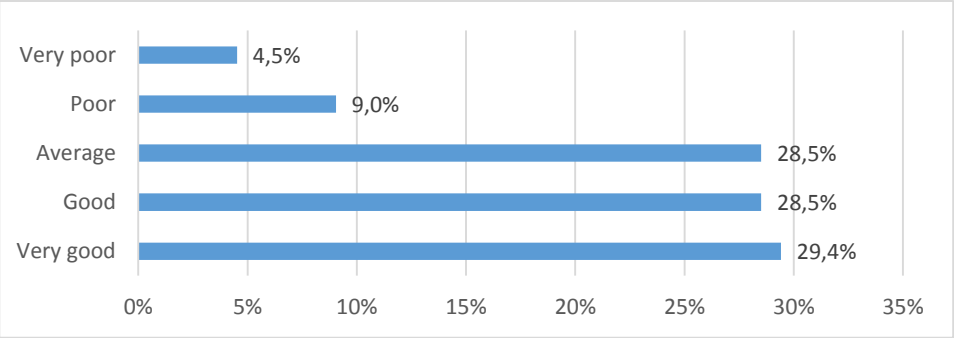

Figure 1. Respondents' answers to the question related to the assessment of their Internet use skills – "How do you assess your Internet use skills?".

Source: own study.

The analysis of responses to the question regarding self-assessment of Internet use skills indicates that the surveyed seniors most often described their digital competences as very good (29.4%) or good (28.5%). A similar percentage of respondents rated them as average (28.5%), while a smaller group provided such responses as poor (9.0%) and very poor (4.5%).

These results suggest that the older people included in the study do not remain completely outside the digital sphere, but participate in the online space to varying degrees. At the same time, a noticeable percentage of "average" and "poor" responses shows that some respondents may still experience difficulties in using the Internet independently and confidently. In the context of further analyses, it will be important to determine whether the subjective assessment of competences translates into the actual level of digital activity.

It should be noted, however, that the declared activity does not necessarily mean full independence or high digital agency. Some older people may use the Internet selectively, limiting it to the simplest functions, avoiding more complex services that require logging in, authorization, or making financial decisions. This phenomenon fits well into the broader concept of digital exclusion, understood not only as a lack of access to technology, but also as a limited level of its effective and safe use. In this sense, the mere presence of seniors in the digital environment does not mean their full integration into digital society.

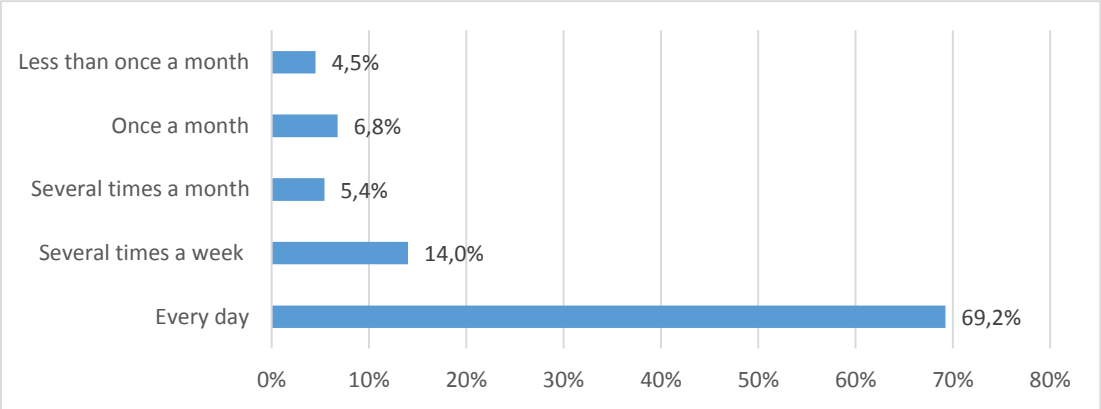

Figure 2. Respondents' answers to the question about the frequency of Internet use – "How often do you use the Internet?".

Source: own study.

The answers to the question about the frequency of Internet use confirm that the Internet is an important element of everyday functioning for most respondents. The largest group of respondents declared using the Internet every day (69.2%), and the next one – several times a week (14.0%). Smaller percentages indicated using the Internet once a month (6.8%), several times a month (5.4%) and less than once a month (4.5%).

Based on the distribution of answers to both questions, it can be concluded that there is a clear tendency for higher self-assessment of digital competences to coexist with more frequent use of the Internet. Among people who assessed their digital literacy as good or very good, daily use of the Internet was dominant, which suggests that higher self-assessment of skills is associated with greater intensity of online activity. In turn, those respondents who assessed their competences as average or poor more often declared less frequent use of the Internet, which may indicate limited confidence in navigating the digital environment. The obtained results can be interpreted as confirmation of hypothesis H1, according to which a higher level of digital competences among seniors promotes more frequent use of the Internet and electronic services.

4.2. Sense of security and experience of threats on the Internet

An important element of the analysis was also the sense of security and the respondents' experiences related to threats and frauds while using the Internet, which was verified by subsequent questions.

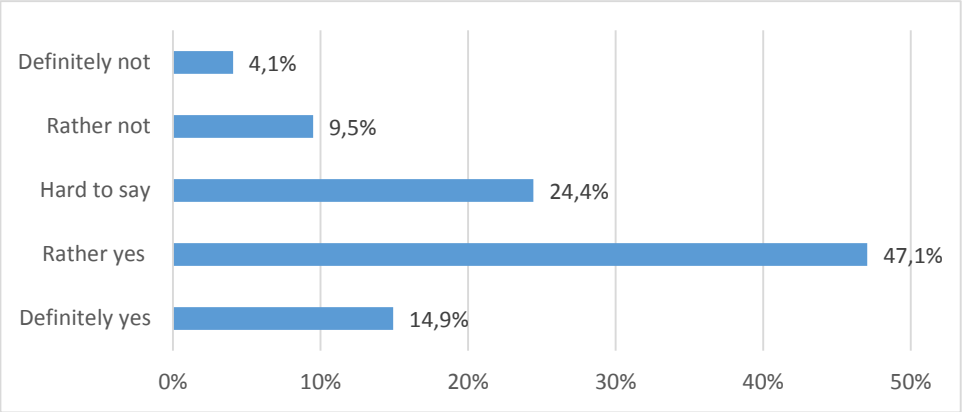

Figure 3. Respondents' answers to the question about their sense of security on the Internet – "Do you feel safe when using the Internet?".

Source: own study.

The results indicate that most seniors declare a relatively good sense of security when using the Internet, but this does not mean full trust in the digital environment. Only 14.9% of subjects responded that they felt definitely safe on the Internet, and 47.1% indicated the answer "rather yes". In total, this gives 61.99% of the surveyed group who declare a positive sense of security. At the same time, 24.43% chose the answer "hard to say", 9.5% "rather not", and 4.1% "definitely not", which shows that for a significant part of the respondents, digital security is not an obvious and unambiguous category.

On this basis, it can be concluded that the level of digital security among seniors is moderate. On the one hand, positive answers predominate, suggesting familiarity with the Internet and some skill in using it, while the share of uncertain and negative answers shows that many seniors use the Internet with some caution. The feeling of security depends not only on the use of the Internet itself, but also on the level of knowledge about threats, personal and social experiences and the level of trust in technology.

This conclusion is further supported by the responses regarding the perception of Internet threats presented in Figure 4.

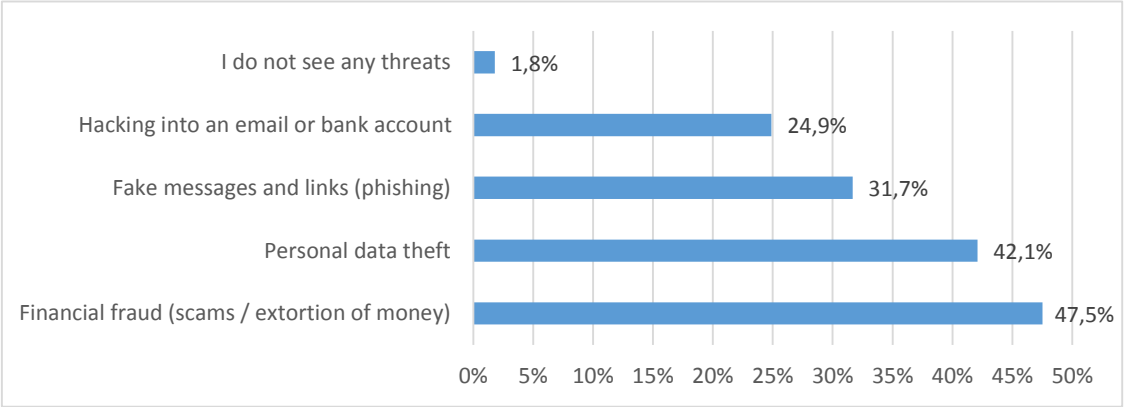

Figure 4. Respondents' answers to the question about the most significant threats on the Internet.

Source: own study.

The largest number of people, 47.5%, cited financial fraud. Second place went to personal data theft, selected by 42.1% of respondents, and third place went to phishing, which is fake messages and links, selected by 31.7% of respondents. This pattern of responses shows that seniors not only use the Internet, but are also able to recognize the most typical forms of cyber threats. The awareness of threats is also confirmed by the responses regarding the experience of fraud attempts presented in Figure 5. 35.3% of the respondents declared personal contact with an attempted online fraud, and 31.2% had heard about such cases. This means that more than half of the respondents had direct or indirect contact with attempted digital abuse. Such experiences may increase caution, but also lead to reduced trust in e-services.

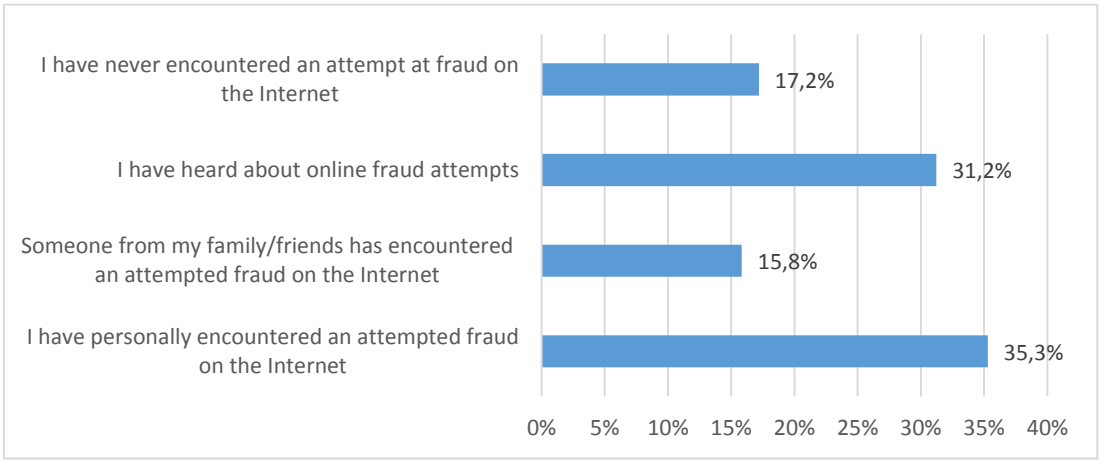

Figure 5. Answers to the question whether the respondent has ever encountered an attempted online fraud – "Have you ever encountered an attempted online fraud?".

Source: own study.

Based on these results, it is clear that seniors are aware of real digital threats, but they do not always have the tools that would allow them to use them effectively and calmly. Such results show that the respondents are aware that using it is associated with a real risk. It is this awareness that may reduce the subjective sense of security, even when using the Internet is regular and efficient.

From the perspective of information security management, it is important that threat awareness can serve a dual purpose. On the one hand, it strengthens caution and encourages more responsible behaviour, but on the other hand, when combined with a low sense of competence, it can lead to anxiety and avoidance of technology. An older person who knows about online scams but does not feel confident enough in using technology may limit their contact with digital services out of fear of financial loss or loss of privacy. As a result, awareness of threats does not always translate into greater activity, but may coexist with a cautious attitude and partial withdrawal.

4.3. Demographic differences in digital activity and security perception

Although aggregate findings provide a useful general overview, a more detailed analysis indicates that older adults do not constitute a uniform group in terms of digital competencies and perceptions of online safety.

A tabulation of gender and self-assessed internet literacy (Figure 1) reveals notable differences in perceived digital proficiency and navigation styles. Although the frequency of daily internet use is comparably high in both groups, male respondents tend to report higher confidence in their digital skills. 34.4% of men rated their competencies as either "very good" or "good". By contrast, female respondents demonstrated a more cautious self-evaluation, with only 27.5% placing themselves in the highest categories, while a larger proportion identified their skills as "average" (41.2%) or "poor/very poor".

Gender also appears to shape the prioritisation of perceived online threats (Figure 4). While financial fraud (including scams and monetary extortion) constitutes the most frequently cited concern across the entire sample (47.5%), women show greater sensitivity to risks related to personal data and identity protection (44.3% among women versus 36.1% among men). These patterns are summarised in Table 2.

Table 2.
Gender-based differences in digital competencies, online threat perception, and sense of security among senior respondents

Category	Skill: very good / good	Skill: average	Threat focus: financial fraud	Threat focus: data theft	Sense of security: safe (yes)
Female	27.5%	41.2%	46.2%	44.3%	59.8%
Male	34.4%	32.8%	50.8%	36.1%	65.6%

Source: Own study.

Educational attainment represents a key structural factor shaping both levels of digital engagement and cybersecurity literacy within the surveyed older population. Respondents with a university degree demonstrate the highest levels of confidence in the digital environment, with 41,5% assessing their competencies as "very good" or "good". Importantly, educational attainment not only influences self-perceived digital skills but also contributes to a more nuanced understanding of cybersecurity mechanisms. While individuals with vocational or primary education tend to focus predominantly on basic financial scams, university-educated seniors exhibit a more sophisticated awareness of structural threats, such as phishing attacks and malicious electronic communications (38.4% awareness within this subgroup). This is presented in table 3.

Table 3.
Educational differences in digital competencies, phishing awareness, and perceived online security among senior respondents

Education level	Skill: very good / good	Threat focus: phishing awareness	Sense of security: safe (Yes)	Sense of security: unsafe / hard to say
Vocational	16.1%	19.4%	48.4%	51.6%
Secondary	26.7%	29.5%	61.3%	38.7%
Higher	41.5%	38.4%	69.6%	30.4%

Source: Own study.

Older adults from rural areas, although still active internet users, report less frequent daily internet use and demonstrate a notably lower sense of digital safety (Figure 3). In this group, the combined share of negative or uncertain responses ("hard to say" or "rather unsafe") reached 43.5%, compared to only 31.2% in urban municipalities. Seniors living in cities benefit from denser social networks, easier access to digital literacy initiatives (e.g., Universities of the Third Age), and more frequent exposure to smart-city solutions (e-banking, e-government services, online public transport systems). As a result, their sense of digital security is reinforced through continuous, supported engagement with technology, whereas rural seniors operate in an environment with more limited institutional support, which increases their perceived vulnerability to cyber threats.

5. Summary and conclusions

The analysis of the study results allows us to conclude that the surveyed seniors are present in the digital space to a significant extent, but their participation is diverse and heterogeneous. The Internet is an important tool for their everyday functioning, which is confirmed by both the high frequency of using the Internet and the relatively positive self-assessment of digital competences. At the same time, the obtained results indicate that this activity does not mean full freedom or complete confidence in using Internet services. Some of the respondents still declare an average or lower level of skills, as well as limited independence in using more advanced digital functions.

An important result of the analysis is the high level of awareness of Internet threats in the surveyed group. The subjects are able to recognize the most common online threats, including financial fraud, personal data theft and phishing. At the same time, a significant number of respondents have encountered fraud attempts directly or indirectly, which further increases their caution towards online services. As a result, the fear of fraud is becoming one of the most important factors limiting the fuller use of digital resources. This means that awareness of

threats does not only have a protective function, but can also lead to distancing oneself from technology and giving up more advanced online activities.

The purpose of the study was to determine the level of digital competences of seniors, their activity in using the Internet and the relationship between awareness of threats and the sense of digital security. The analysis of the results allowed us to achieve this objective, as it revealed both the scale of everyday use of the Internet and the perception of threats, experiences of fraud and limitations related to online services. The study showed that seniors are active Internet users, but their functioning in the digital space is largely dependent on trust, security and previous experience.

The obtained results allow us to consider hypothesis H1 as confirmed. A higher level of digital competence among seniors is associated with more frequent use of the Internet and electronic services. The respondents who assessed their own skills better were more likely to declare regular online activity and greater willingness to use digital tools. Hypothesis H2 is also confirmed by the study results. The level of awareness of threats and the sense of digital security remain significantly related to the activity of seniors in using Internet services. People who are better at recognizing threats and declare a higher level of security are more likely to use e-services, while a lower sense of security fosters a cautious attitude and limits digital activity.

The obtained results allow us to conclude that the activity of seniors in using Internet services remains strongly linked to the level of their digital literacy, awareness of threats and sense of security. Seniors are not a passive group in the face of digitalization - many of them use the Internet regularly and use electronic services in their daily lives. At the same time, however, the presence of concerns, lack of full certainty and technical difficulties indicate that the process of their digital integration has not yet been completed.

The results obtained in this study are consistent with findings presented in previous literature concerning digital literacy and online security among older adults. Similar relationships between digital competences and the intensity of Internet use were identified by van Deursen and Helsper (2015), who emphasized that higher digital skills increase both the frequency and diversity of online activities among seniors. Comparable conclusions were also presented by Hargittai and Dobransky (2017), who demonstrated that digital inequalities among older adults are strongly associated with education level, previous technological experience and self-confidence in using digital tools.

The present study also confirms observations described by Olphert and Damodaran (2013), according to which awareness of online threats may simultaneously increase caution and reduce willingness to engage in more advanced digital activities. Similar conclusions regarding the importance of digital security awareness for safe online participation were formulated in reports by ENISA (2024) and NASK (2024), which highlighted that seniors remain one of the groups particularly vulnerable to phishing, financial fraud and social engineering attacks.

Therefore, the obtained findings support the broader conclusion present in the literature that effective digital inclusion of seniors requires not only access to technology, but also continuous educational support, development of digital competences and strengthening users' sense of online security.

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AGILE FRAMEWORK FOR QUALITY AND INNOVATION IN EXTENDED LIFE CYCLE ASSESSMENT: THEORETICAL APPROACH

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Purpose: The paper presents a theoretical approach for extended Life Cycle Assessment (LCA): Quality (Q) and Innovation (I) in LCA (QILCA). This model (QILCA) extended to include product innovativeness in the era of mass personalization and Agile product design. Interest in the application of Agile design techniques in various design contexts has grown in recent years, becoming a promising trend in many areas, including customer (user)–product interactions. A product design strategy that incorporates the Agile concept may be the key to success in the age of mass product personalization and relationship marketing between manufacturers and customers (product owners).
Design/methodology/approach: The work is based on applying the principles of agile product development to the LCA phase of product prototyping, which allows us to produce a test-ready design in a short time, with the ability to make changes at any stage of the design process, while taking customer requirements into account.
Findings: Based on a segmented review of the literature, this paper discusses the Agile approach during the prototyping phase from a QILCA perspective.
Research limitations/implications: The presented assumptions and applications of the Agile approach to extended LCA constitute a framework for further research.
Practical implications: The proposed QILCA framework extends the scope of traditional product improvement by including quality, innovation, and LCA, also achieving increasingly higher standards through new or improved product features that are considered innovative in sustainable business.
Originality/value: The Agile approach is being applied to a growing range of product development. Although its (brief) history dates to AI projects, it is now being applied to the design (and improvement) of products in other industries. The authors contribute to the first discussions about the feasibility of implementing the Agile approach to product development.
Keywords: product improvement, Life Cycle Assessment (LCA), Agile.
Category of the paper: conceptual work.

1. Introduction

With the development of remote communication technologies and the intense competition among manufacturers for consumer markets, user (customer) involvement at the product design stage has become important for manufacturers in their pursuit of business objectives. However, the strong political radicalism in favor of environmental protection has led businesses to invest in reducing the negative environmental impact of products throughout their entire life cycle (Burchart-Korol et al., 2020). In corporate (manufacturer) efforts toward environmental protection, cooperation with customers (product users) is essential to create products that meet their needs. Customers expect highly innovative products from manufacturers. Their needs are often aspirations or dreams that producers attempt to realize; therefore, an Agile approach is necessary in the process of product improvement. To ensure that product innovation remains under control, a Life Cycle Assessment (LCA) methodology is needed, assuming that improved products will be recyclable, reusable, or even environmentally "friendly" at every stage of their life cycle. Enterprises monitor the impact of products throughout their entire life cycle, and the LCA methodology is a helpful and continuously evolving tool for this purpose.

Previously, the authors of this publication (we) examined the evolution of LCA frameworks (Siwiec, Pacana 2025a), proposing the integration of: (i) quality criteria into the LCA methodology at the product design stage, introducing the QLCA model (Gajdzik, Siwiec et al. 2024); (ii) cost evaluation (CQ-LCA) (Gawlik et al., 2024; Siwiec, Gajdzik, Pacana et al., 2025; Siwiec, Pacana, 2025b); and (iii) design thinking (DT-QLCA) (Siwiec, Gajdzik, Gawlik et al., 2025; Pacana et al., 2023). The authors have now added to the QLCA model criteria that serve as indicators of product competitiveness and innovativeness at the product improvement stage, following the Agile approach. The proposed extended LCA framework, incorporating quality and innovation aspects of products, has been named the QILCA model. The developed model emphasizes the necessity—particularly in many cases of product improvement—of applying an iterative (nonlinear) improvement process based on Agile methodologies (Fowler, Highsmith, 2001). Agile is a flexible project management approach focused on delivering products through iterative and incremental processes of improvement (Sadia et al., 2021).

The main objective of this publication is to present Agile-based product development within an LCA framework extended to include Quality (Q) and Innovation (I) aspects of designed products. Although many Agile practices existed in project management, the Agile approach had not yet been introduced into LCA at the stages of product design and improvement.

The research gap addressed in this paper lies in the lack of an integrated methodological framework that combines Life Cycle Assessment (LCA) with quality and innovation parameters during the early stages of product design (Balcioglu et al., 2025; Dong et al., 2025; Siwiec, Gajdzik, Gawlik et al., 2025), specifically under Agile project management principles

(Sahu, 2025). While LCA has traditionally focused on environmental impact across the product life cycle, existing literature does not provide systematic approaches that also incorporate iterative customer engagement, dynamic product refinement, and innovation assessment within sustainable design processes (Bossek et al., 2023). Furthermore, Agile methods, though widely applied in software and organizational development, have not yet been effectively operationalized in the context of environmental and quality-driven product optimization (Almalki, 2025; Koudriachov et al., 2025). This gap highlights the need for a holistic model—such as QILCA —that enables rapid prototyping and decision-making based on environmental, quality, and innovation criteria simultaneously.

Based on the current body of scientific publications, it is not yet possible to speak of a systematic Agile approach to the development of new products at the stage of their design and assessment of environmental impact throughout the entire life cycle (enterprises are only beginning to adopt such an approach). In practice, companies apply partial solutions established by individual project teams and R&D managers, based on best practices developed in previous product improvement projects, with significant customer involvement at various stages of refining product functions and specifying the features of improved products.

While open innovation literature is validated to show increased focus on external knowledge streams and customers' involvement in product development (Du et al., 2025; Jiang, Ma, 2025; Steinbeck, 2025; Suzuki, 2025; Tantiathimongkhon et al., 2025), there is still lack research with detailed frameworks of Agile design in sustainability-focused methodologies. Current research avoids specifying open innovation as a managerial or strategic method (Quero et al., 2025; Sabino et al., 2025; Steinbeck, 2025; Tolou-Shams et al., 2025) but doesn't incorporate it with collaborative working instruments such as Agile design or Life Cycle Assessment that facilitate interactive co-creation among stakeholders. Hence, little is known about how open innovation can be efficiently integrated in decision-support models that simultaneously address quality, environmental sustainability, and product innovativeness. The lack of integrative models constrains theoretical advancement as well as open innovation's practical use in sustainable product development.

The next structure of the article included: Section 2. Theoretical approach to product improvement through Agile Design in Quality and Innovations in Life Cycle Assessment (QLCA); Section 3. Discussion about presented theoretical approach; and Section 4. Conclusion.

2. Theoretical approach to product improvement through Agile in Quality and Innovations in Life Cycle Assessment (QILCA)

The diversity of customer requirements, as well as increasing global competitiveness and dynamic market trends, lead companies to direct their product development strategies toward serving individual customers at costs comparable to mass production (Paritala et al., 2017). Customer needs are diverse, and manufactured products should respond to these needs (Lin et al., 2017); hence, it is necessary to involve customers (users) in the product improvement process already at the design stage.

In recent decades, advancements in production lines and supply chains, strongly supported by automation and Industry 4.0 technologies, have provided enterprises with the necessary process flexibility to deliver products to customers with efficiency comparable to both mass production and market position (Gajdzik, 2022; Gajdzik, Jaciow et al., 2024; Wang et al., 2017).

Referring to (Ozdemir et al., 2022), it is worth emphasizing the distinction between customization and mass customization (MC). Product customization dates back to the era of handcrafted, made-to-order goods, where craftsmanship and additional labor naturally resulted in high costs. In contrast, MC refers to affordable customization, making it an attractive and feasible business strategy (Kumar, 2007). However, in mass customization, companies must strongly focus on minimizing the environmental impact of improved products. Failing to adopt this approach already at the product design stage may negatively affect business competitiveness. Mass customization must be consciously controlled and implemented with consideration of the many factors involved in this process (multiple variables must be taken into account in decision-making) (Saniuk et al., 2020). One of the key determinants at the product design stage is the reduction of environmental impacts while ensuring high product quality and attributes perceived as innovative in consumer markets.

Product design and improvement should be carried out in such a way as to enable manufacturers to balance environmental impacts with the characteristics of improved (innovative) products while meeting customer requirements (Gajdzik, Wolniak, 2022a, 2022b). This is achievable if manufacturers consider business requirements, customer demands, and environmental aspects already at the design stage. Product improvement should follow the principles of the LCA methodology, with strong support from multifunctional (cross-functional) project teams capable of applying Agile approaches and building customer engagement during product design (and improvement), making customers aware of the interactions between environmental, quality, and innovation criteria throughout the product life cycle. According to (de Bruijn et al., 2002), intensive interaction between the LCA client and LCA researchers is essential. Such teams should include production engineers and IT specialists, due to the digitalization of production processes and products themselves (in selected consumer markets), as well as R&D and quality (product development) staff,

and representatives of the client (ordering party) (Gajdzik, Wolniak, 2022a). Team composition in Agile-based LCA methodology must remain flexible, depending on the type of product, degree of innovation, environmental impact, and other factors. This flexibility in teamwork stems from the Agile concept itself, which is applied to developmental or organizational projects. Creativity is a key factor in this design process (Gajdzik, Wolniak, 2022b).

According to (Stare, 2014), based on this author's literature review, the Agile concept originates from agile methods of software development (first references to such an approach appeared as early as the 1980s). Agile (concurrent) methods emphasized the simultaneous execution of traditionally sequential project tasks ("fountain" instead of "waterfall") and continuous coordination among participants. In this sense, agile methods were comparable to concurrent engineering, which also emerged in the 1980s. In 1986, an article entitled The New New Product Development Game was published in the Harvard Business Review (Takeuchi, Nonaka, 1986). Although its initial impact was modest, the concepts it introduced later inspired the pioneers of Agile in the United States, who became particularly interested in the iterative and team-based practices of leading Japanese companies described in the article. Since then, an increasing number of companies in Japan, followed by those in the United States and other parts of the world, began to place greater emphasis on improving both workforce capabilities and process efficiency.

Initially, the Agile approach was primarily applied in IT projects, and its widespread adoption occurred only after 2001. In that year, the Agile Manifesto was published (Fowler, Highsmith, 2001), in which a group of designers (17 software engineers) proposed iterative principles for design (software development).

Based on a literature review covering the period from the publication of the Agile Manifesto in February 2001 through December 2024, the Web of Science (WoS) database was searched according to four scopes: (i) using only the keyword "Agile", (ii) using the keywords "Agile" AND "Project", (iii) using the keywords "Agile" AND "Product Development", and (iv) "Agile" AND "Product Development" AND "LCA". Keywords were searched in the title, abstract, and author keywords. The results of this analysis are presented in Table 1.

Table 1.
Results of the literature review about Agile in the period from 2021 to 2024

Field	Number of papers	Paper with highest citations (Top 5)
Agile	8682	(Aheleroff et al., 2021; H. Li et al., 2021; M. Li et al., 2021; Modgil et al., 2022; Troise et al., 2022)
Agile AND Project	1836	(Cico et al., 2021; Edison et al., 2022; Filippetto et al., 2021; Malik et al., 2021; Marzi et al., 2021)
Agile AND Product Development	722	(Buchanan et al., 2023; Cico et al., 2021; Cooper, 2021; Y. Li et al., 2021; Marzi et al., 2021)
Agile AND Product Development AND LCA	4	(Bhagwat et al., 2021; Camañes et al., 2024; Y. Li et al., 2021; Rinne et al., 2022)

Source: own elaboration based on WoS.

The papers of Y. Li et al. (2021 and Bhagwat et al. (2021) provide examples of higher-order principles as an attempt to contrast Agile product development. Through the two articles, iterative experimentation and interdisciplinary integration are performed as an attempt to address optimization of bioconversion pathways—lignocellulosic biomass to lactic acid and 3-hydroxypropionic acid, respectively. These studies are exemplars of Agile methodology in that they compartmentalized the problem of producing sustainable chemistry into discrete, bite-sized pieces such as feedstock discovery, microbial design, and downstream processing. Some overlap between process simulation and experimental data existed to allow incremental improvement, e.g., Agile sprint cycles. Bhagwat et al. (2021) describe Agile flexibility in terms of combining techno-economic and life cycle assessment in the initial development stages in such a manner that technical viability is balanced against sustainability goals and stakeholder requirements. Interaction among iterative design, environmental research, and stakeholder analysis is a more suitable model of Agile product development for bio industrial innovation.

Camanes et al. (2024) place their work within an adaptive and sustainable product design process. They build an eco-design system based on modularity and professional software support to facilitate rapid prototyping and concurrent decision-making in design in real-time with sustainability analysis. The methodology assists design teams in integrating eco-factors into product development processes continuously practice entirely in line with Agile principles. By enabling open decision-making and time-to-iteration reduction during designing, their software-enabled eco-design capability truly does make sustainability an integral, forward-looking aspect of Agile product design and not an afterthought in terms of regulatory policy. Such synergism is an accurate reflection of the capability for Agile principles to be strategically embraced for long-term innovation by leveraging digital tools as well as systems' feedback (Camañes et al., 2024).

The essence of the Agile approach involves the continuous updating of implementation and detailed planning of smaller cycles (iterations) to carry out a project in line with current results, lessons learned, and new ideas from design participants (members of the project team) and the engaged client. Agile offers a new way of thinking, based on a set of principles presented in Table 2, which emphasizes the ability to adapt a project to the needs of design participants for an improved product through the continuous refinement of designs (prototypes). This approach places strong emphasis on delivering value to customers quickly and fostering close collaboration with clients, who actively participate in product improvement (Takeuchi, Nonaka, 1986).

Table 2.
Characteristics of the Agile Approach in Product Improvement Design

Agile approach	Description in context of product improvement design
Requirements/ specifications	Agile follows a customer-oriented philosophy with the client at the center of the development process. The approach is dependent on having in-depth familiarity with user requirements and the capacity to react speedily based on their fluctuating demands. Agile encourages frequent iteration, constant early delivery, and constant checking to the extent that the existing product aligns with client goals. One of the major aspects of this process is that the client is directly involved in every step of each product iteration. As the end product is normally not even appropriately defined to start with, Agile employs an incremental approach wherein every iteration possesses a working subset of the product that is gradually polished further. This is made possible through intense interaction between the client and project team, enabling open sharing of ideas and joint problem-solving. Agile teams operate in a flat organizational structure, which enables adaptive working in response to new information and evolving conditions. Initial requirements are established and decomposed into sprint tasks at the beginning. These are not fixed; instead, they are refined through iterative cycles, with lower-priority elements eliminated early in the planning phase to create a well-defined and streamlined path toward the most critical product functionalities.
Project schedule	Agile projects are organized into brief, time-boxed iterations—usually not exceeding eight weeks—fostering ongoing, evolutionary refinement of existing products rather than revolutionary overhaul. Refining tends to target single functions or related sets of functions within products already in the market, with change potentially transferring into redesigning basic structural components. While a generic project schedule is established early on, in-iteration individual planning for every iteration is done just-in-time by the team, allowing for instant response to changing requirements and closeness to the product owner or customer. Perhaps the most distinctive characteristic feature of Agile is autonomy and flexibility granted to self-maneuvering teams who plan their work and task assignments themselves. In the interest of ongoing quality control, testing is planned and carried out during the development process effortlessly. Furthermore, Agile promotes open and communicative working in terms of iterative advancement and intimate customer focus, and this evokes imagination, collective ownership, and high-performance output that tends to go beyond original expectations.
Teamwork and collaboration with client	Product development under the Agile system is a spin-off of collaborative efforts by an interdisciplinary team of professionals whose strengths complement each other in various fields. The team not only carries the technical burden of product development, but also its market viability and competitiveness. One of the characteristics of Agile product development is the constant seeking of solutions in the design process, where constructive confrontation—open and intentional debate between differing opinions—is freely encouraged as a way of generating innovation and resolving design issues. Members collaborate in pairs, which enhances synergy, enables sharing of knowledge, and maximizes overall quality of output. Regular stand-up meetings allow for live tracking of progress, task definition, and quick resolution of issues, thereby allowing for transparency and keeping the team focused. Frequent sharing of failures and process inefficiencies is the foundation of Agile culture, which does not treat them as failures but as improvement opportunities fuelling continuous improvement. Visual management aids such as Kanban boards support this by putting workflow into synchronization, bringing issues to the surface, and inspiring team solidarity. Each iteration closes with a scheduled retrospective, at which point the team inspects the performance of its processes, identifies bottlenecks, and defines improvements—a roadmap for eventual and incremental adjustment.

Cont. table 2.

Client collaboration/ engagement	The client, whether a final user or special stakeholder, is a key player at each phase of the project life cycle throughout the Agile development lifecycle. As an interactive and regular participant, the customer is part of the project team and easily accessible to provide feedback, assist in interpreting requirements, and play a part in the changing product. This also comes into play in setting test procedures, where clients with suitable domain knowledge help to explain initial ideas into concrete expectations and suggest major variations. These iterative cycles increasingly evolve fuzzy assumptions into concrete, actionable development goals. Frequent and open communication maintains the client continually informed of progress, permitting prompt review of halfway results and identification of inconsistencies or shortfalls. In this manner, improvement is a process of iterative excellence, whereby every iteration becomes the next one's benchmark for greater performance and value. This model condenses essentially uncertainty and risks by creating frequent, timely understanding for both the team and the client in terms of what has already been accomplished, and which ones remain to be finished. The result is a very malleable, open, customer-centric process which is responsive and long-term in value.

Source: own elaboration based on (Biały et al., 2023; Boehm, Turner, 2005; Brandon, 2005; Denning, 2010; Feldman, 2018; Flewelling, 2018; Forsberg et al., 2005; Gajdzik, Kopeć, 2022; Gibbs, 2006; Kansy, 2024; Lindstrom, Jeffries, 2004; Meade, Sarkis, 1999; Rothman, 2007; Stare, 2014; Thomsett, 2002; Wysocki, 2019; Stare, 2014).

According to (Wysocki, 2019), the Agile approach can serve as a method for improving products during their design and prototyping stages. A strong user focus is essential, which is why the project team invites a representative of the product's end users to collaborate. The user regularly reviews partial project outcomes to ensure the final product better aligns with customer requirements. Product improvement iterations are repeated whenever the client is not satisfied with the results. Wysocki (2019) also highlights differences between the traditional Waterfall design approach and Agile. These differences include the level of planning detail, risk management, collaboration with the client, and task sequencing. In Waterfall design, project requirements are clearly defined before initiation, and significant changes are not anticipated during execution. Projects are typically routine and repetitive, and project teams often reuse standard design procedures. This approach is linear and sequential (step-by-step), with each phase requiring completion before the next begins. In contrast, in Agile design, client requirements are only partially known, and the process allows for additional iterations during product refinement. Product improvements (including multiple product functions) are structured into iterations known as sprints (Schwaber and Beedle 2001), following the Scrum methodology. At the beginning of each sprint, a backlog of customer requirements is created, specifying the product features targeted for improvement. Members of the Developers Team may introduce a wide range of changes within individual sprints under Scrum (Klaus-Rosińska, Gąsiorowska, 2025; Sadullayev, 2025). In addition to the product owner, who represents client requirements, there is also a Scrum Master, who coordinates Scrum, resolves obstacles, and facilitates communication among stakeholders (Schwaber, Sutherland, 2017).

Sprints form part of the Agile approach and are components of iterations. Sprints are fixed work intervals limited to a specified period (typically weeks), whereas iterations may last longer. Sprints consist of defined activities such as sprint planning and sprint review, while iterations do not necessarily include these formal structures. Iterations are usually

predetermined for the duration of the project, whereas sprint lengths may vary depending on project requirements. In summary, iterations span the overall project timeline, while sprints are shorter time boxes for achieving specific goals. Both sprints and iterations are flexible work structures that can be applied in any type of project or business domain, including new product development. Their structured nature ensures frequent project visibility for teams, continuous feedback collection, and rapid responses to errors, new requirements, and potential risks (Madya et al., 2022; Radhakrishnan, Koumaditis, 2020).

The Agile approach according to the Scrum methodology involves the following stages (Schwaber, Sutherland, 2017):

1. **Defining the project goal**: determining what must be accomplished (establishing what the team is to deliver in each iteration). The execution of this first stage (goal and scope definition) is closely tied to task formulation. At this stage, the Product Backlog is created. According to (de Bruijn et al., 2002), accurate forecasting is crucial at this point, as every task involves a degree of risk. Unjustified simplifications should be avoided, as should extrapolation of LCA results. For example, if the analysis aims to provide a general comparison of two product system types, comparing only a few specific cases is insufficient. The process design must also specify how a task may be modified in light of new information, such as changes in the intended use of LCA, stakeholder involvement, or LCA quality requirements.
2. **Sprint Planning**: establishing the sprint duration and making organizational arrangements, such as setting team pairings or communication formats. Team members are introduced to the Scrum Master, who supervises the project. "Sprints are the heartbeat of Scrum, where ideas are turned into value" (Schwaber, Sutherland, 2017). A new Sprint begins immediately after the conclusion of the previous Sprint. In the context of LCA extended with Q and I, the threefold aspects (quality, innovation, and environment) become key considerations in product improvement.
3. **Sprint Backlog**: identifying what must be completed within the Sprint. The Sprint Goal, selected Product Backlog items, and the delivery plan together form the Sprint Backlog. Planning meetings are organized where the team selects tasks from the Product Backlog (the prioritized task list prepared by the Product Owner). At this stage, tasks are divided into smaller, manageable parts called "user stories." In product design and improvement within LCA, a holistic perspective is essential, considering all product stages from cradle to grave.
4. **Sprint Execution and Daily Scrums**: the Daily Scrum focuses on progress toward the Sprint Goal and sets an actionable plan for the next day's work. Daily reporting of tasks and results improves focus and work quality. These meetings enhance communication, identify obstacles, support quick decision-making, and reduce the need for additional meetings. Development occurs within iterations (Sprints), typically lasting 1-4 weeks,

during which the team works on selected tasks from the Sprint Backlog. Frequent team communication is a key success factor.

5. **Sprint Review**: the review is the penultimate event of a Sprint. Its purpose is to evaluate Sprint results and determine future adjustments. The Scrum Team presents its work to key stakeholders, and progress toward the Product Goal is discussed. In an LCA-based approach, the Scrum Team and stakeholders assess Sprint achievements and review changes in the product's environmental impact. Based on this information, participants jointly determine further steps to minimize negative environmental impacts. The Product Backlog may also be updated to reflect new opportunities.
6. **Sprint Retrospective**: during this final stage, the team discusses what went well, what could be improved, and what actions should be implemented in future project work. The goal is continuous improvement of teamwork and product development. The Sprint Retrospective concludes the Sprint.

The Agile approach can be summarized through several key characteristics (Table 3).

Table 3.
Key Features of Agile in Product Improvement

Feature	Description
Flexibility and Adaptability	Agile enables rapid responses to changes in requirements or priorities, which is crucial in dynamic projects.
Frequent Delivery of Functionality	Through its iterative approach, functional elements of the product are delivered regularly (e.g., each sprint), allowing for quick testing and feedback collection.
Strong Collaboration with the Client	The client remains engaged throughout the entire project, helping to create a product that meets actual needs.
Risk Identification and Problem Solving	Iterations make it possible to quickly detect and resolve issues before they escalate.
Transparency	Regular meetings (e.g., Daily Scrum) and the visibility of the backlog ensure that progress is clear to all stakeholders.

Source: Own work on basis: (Brandon, 2005; Forsberg et al., 2005; Lindstrom, Jeffries, 2004; Rothman, 2007; Schwaber, Sutherland, 2017; Wysocki, 2019).

Although the Agile approach has several specific characteristics (principles) related to iteration, teamwork (teams focused on product improvement), and collaboration with the client (the client's representative is a permanent team member), it is this last feature that constitutes the essence of product improvement. According to Agile methodology, it is recommended—even necessary—to strengthen collaboration with the client or their representative. The representative must be available 24/7 to provide additional information about the functions (features) of the improved product (Meade, Sarkis, 1999). The client (or their representative) is a permanent member of the team and actively participates in daily product improvement activities (Brandon, 2005). Their involvement must be strong enough to allow them to propose changes and take part in their evaluation (adding value). The client or their representative should participate in the development of testing procedures (Gibbs, 2006), as this gives them direct influence over product development through regular testing of intermediate outcomes and reporting shortcomings and errors to the team (Brandon, 2005). Agile enables teams to

maximize product value through flexible project work while adapting the design to client needs, thus facilitating the effective delivery of high-quality and innovative improved products (Cao et al., 2009).

The Agile approach must be adapted to specific projects and their implementation conditions in different product improvement contexts to ensure optimal outcomes (Biały et al., 2023). Agile methodologies are gaining increasing recognition for their ability to respond rapidly to customer needs regarding product functions or features (continuous product improvement processes), particularly in Industry 4.0. Agile aims to enhance performance and the quality of final deliverables by enabling development teams to respond effectively to changes and progressively refine customer expectations, ensuring maximum end-user satisfaction and continuous feedback (reporting progress in project work) (Tripathi, Chattopadhyaya, Bhadauria et al., 2021; Tripathi, Chattopadhyaya, Mukhopadhyay et al., 2021).

Open innovation theory evolved as the core theme of innovation management to replace the earlier R&D closed system operation mainly from internal sources (Sabino et al., 2025; Szromek, Bugdol, 2025). Chesbrough elaborated further that open innovation is a managed inflow and outflow of knowledge beyond the company boundary for the intent of triggering internal innovation and further external use of innovation markets. Under this paradigm, companies no longer need to own development teams or research labs; instead, they create networks of partners that include research institutions, universities, start-ups, competitors, and customers. Knowledge and technology resources thus flow between internal and external collaboration partners to develop a dynamic collaboration innovation network (Brilhante, Romero, 2025; Sirolli et al., 2025; Steinbeck, 2025; Yun et al., 2023; Yun, Zhao, 2020; J. Zhou et al., 2025). Theoretical underpinnings of open innovation have their roots in network theory, absorptive capacity, and evolutionary economics. Network theory revolves around interfirm relations with the objective of making and sharing knowledge as well as depicting how collaborative network firms can gain access to a wider array of technological capabilities. Absorptive capacity is all about how the firm can recognize, absorb, and exploit knowledge from outside, which is at the heart of open innovation. Evolutionary economics does suggest the path-dependent and cumulative process of innovation and the extrapolation of the firms' learning and recombinant ability with the assistance of the external partners. The two theory foundations are intellectual underpinnings of the collaborative and system-scope of the open innovation (Delay et al., 2025; Ullah et al., 2025; X. Xie, Yu, 2025).

Open innovation is typically divided into two complementary processes, i.e., inbound and outbound. Looking outward for outside knowledge using, for example, engaging customers through co-designing, purchasing technology from research organizations, or utilizing online platforms to crowd-source ideas makes up inbound open innovation. Spilling inside knowledge using, for example, licensing technologies, spinning off companies, or sharing R&D results with partners makes up outbound open innovation. Hybrid categories, or paired processes for

some purpose, both have levels and are particularly applicable in tomorrow's companies where sharing knowledge and co-evolving is key to success in sustainability initiatives (Rodríguez-Núñez et al., 2025; Salvalai et al., 2025; X. Wang, Luan, 2025).

Increased value in open innovation is purely attributed to Industry 4.0 challenges and the world's sustainability agenda. The need to supply personalized products and rapid-changing technology compels companies to think beyond their fences in order to obtain complementary capabilities and innovate in cutting cycles. At the same time, sustainable development poses solutions for which no single actor can have anything to contribute, since environmental and societal issues traverse entire value chains. That is where open innovation increasingly entered realms such as a circular economy, eco-innovation, and life cycle assessment. Collaborative innovation networks enable the company to engineer solutions that address not only customers' requirements but also rules', nature's, and society's needs (Huynh et al., 2025; Moradi, Hepsø, 2025; Yun et al., 2020, 2023).

For this purpose, the integration of open innovation concepts and Agile and QILCA model serves the optimal theoretical basis for the given framework. Incremental development and continuous involvement of stakeholders are the focus points of Agile design, whereas QILCA incorporates innovation, quality, and environmental factors in designing products. The model incorporates the open innovation approach through the integration of customer input and external knowledge in every step of the design. It displays how co-creation openness and knowledge exchange can be traced to create sustainable, innovative, and high-quality products in turbulent market conditions (Carbonell-Alcocer et al., 2024; Gajdzik, Siwiec et al., 2024; Jiang et al., 2025; Siwiec, Gajdzik, Gawlik et al., 2025; L. Zhou et al., 2024). Table 4 presents example criteria for evaluating product improvement potential in terms of quality, innovation, and environmental impact.

Table 4.
Framework of QILCA: Examples of Product Evaluation Criteria

Criteria Category	Example Indicators
Quality (Q)	- Ease of use (user-friendliness) - Functional reliability - Precision and accuracy of performance - Ergonomics and user comfort - Resistance to external conditions (e.g. dust, humidity, temperature) - Long-term consistency of performance - Aesthetic quality and material finish
Innovativeness/Innovations (I)	- Ease of assembly and installation - Level of technological complexity - Degree of automation - Productivity and throughput - Operational lifespan - Ease and frequency of servicing - Ease of repair - User safety and integrated safety mechanisms - Ease of maintenance - Modularity and adaptability - Integration with digital technologies (e.g. IoT, smart systems)

Cont. table 4.

Environmental Aspects (E)	- Emission of harmful substances or by-products - Energy consumption during operation - Energy loss or inefficiency - Use of recyclable materials - Reusability of components - Environmental footprint across the life cycle (LCA) - Compliance with environmental regulations - Potential for circular reuse or remanufacturing - Use of eco-friendly or biodegradable materials - Packaging sustainability (e.g. minimal, recyclable)

Source: own elaboration based on (Ekmekci, Nebati, 2019; Koomson, 2025; Luo et al., 2025; Moses et al., 2025; Qin, 2025; Shivani, 2025; Z. Xie, Yang, 2025).

Complex projects in Agile are carried out using single teams as well as larger units (teams of teams). One product is one backlog. All Scrum teams work on a shared product backlog. Hierarchy is kept to a minimum to avoid unnecessary bureaucracy. Teams regularly synchronize (e.g., through Scrum of Scrums meetings).

Application example: Product improvement projects with high interdependence between components. Teams, called "Squads", are autonomous and responsible for specific product functions. "Tribes" are groups of Squads working toward a common goal. Additionally, "Chapters" and "Guilds" facilitate knowledge-sharing across teams. Teams maintain a high degree of autonomy while remaining aligned with organizational objectives. Product design relies heavily on collaboration and cross-functional teamwork. During the planning phase, sprints are defined, with each sprint dedicated to enhancing specific product functions assigned to the project team. The team is responsible not only for the successful completion of the project but also for ensuring the product's competitiveness and success in the market (Forsberg et al., 2005). Constructive confrontation is a standard method for generating new ideas and solving problems (Forsberg et al., 2005). Work is performed in pairs rather than individually (Brandon, 2005; Lindstrom, Jeffries, 2004; Rothman, 2007). The team discusses work results, ideas, and product improvement challenges (Rothman, 2007). Team members regularly review their mistakes and learn from them—after each iteration, they evaluate the adequacy of assessments, methods, and techniques, identify errors, and plan future improvements (Boehm, Turner, 2005).

Given the complexity and specificity of projects, sprints are defined to help the development team organize and break down the project into smaller, autonomous tasks. At this stage, both the team and the client's representative (product user) must establish an initial set of key (potential) quality, innovation, and environmental criteria for the improved product. Iterations focus on achieving a satisfactory level of product quality and business competitiveness while designing an environmentally friendly product. The QILCA model ensures more precise product improvement by incorporating critical improvement areas that meet customer needs while safeguarding the environment, with product innovativeness serving as a key factor for manufacturer competitiveness (Siwiec, Pacana, 2024a, 2024b). In line with the Agile approach, the client participates in product verification against power of influence of quality, innovation, and environmental criteria. Figure 1 presents the simplified QILCA model in Agile Design.

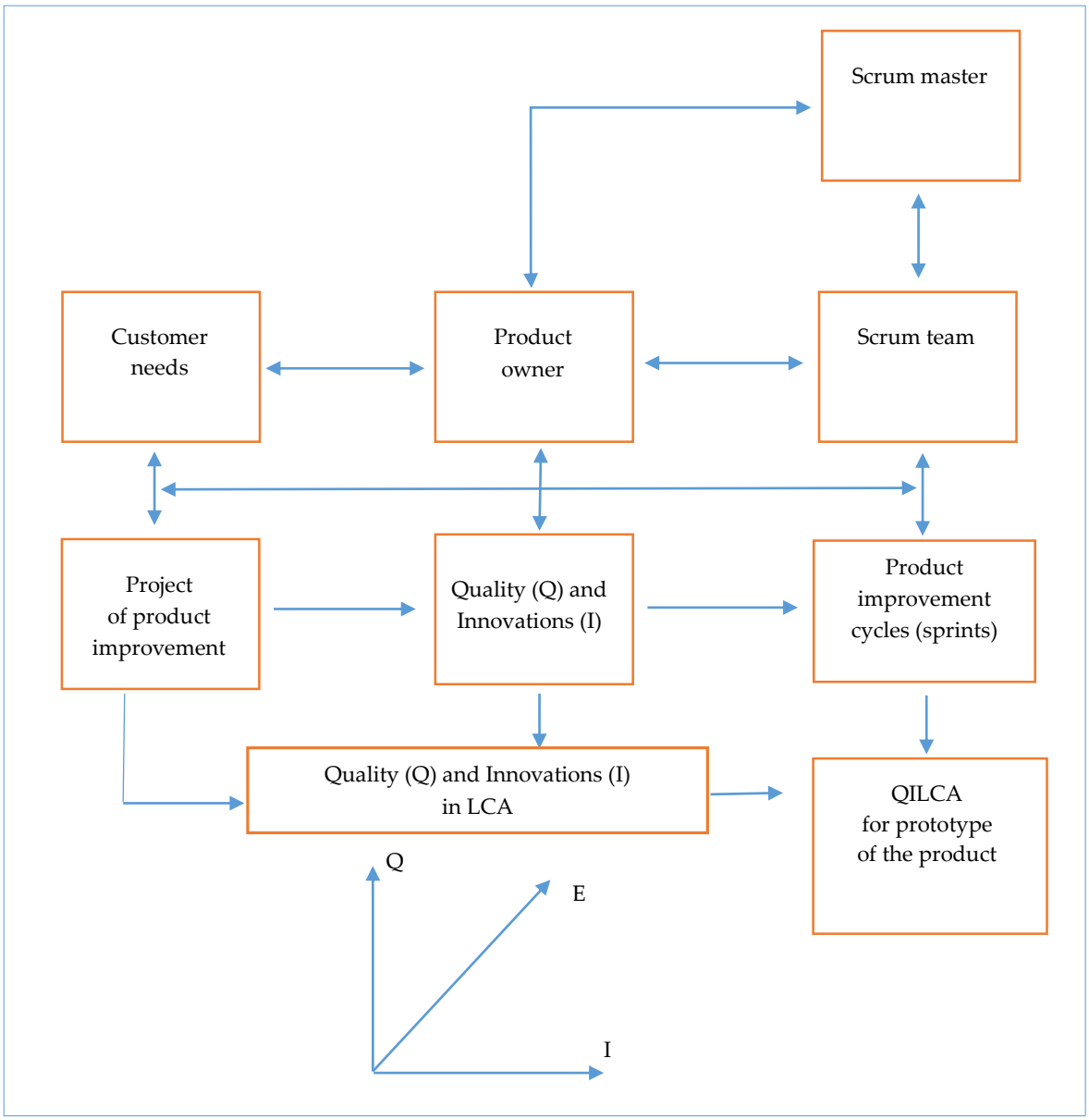

Figure 1. Simplified QILCA model in Agile Design.

Source: own elaboration.

3. Discussion

Presentation of results captures the dramatic extension of the classical LCA philosophy to encompass product quality (Q) and innovation (I) dimensions in Agile principles. Convergence of the three parties—quality, innovation, and ecoburden—presents a tale of shift away from classical linear life cycle calculation methods towards a dynamic cyclical decision-support approach embraced already at the conceptual design stage. Literature review evidence (Table 1) supports prevalence of limited number of studies that integrate Agile with LCA and innovation, thereby justifying the need for proposed QILCA model as a counter to the

researched existing gap. A broad scope of the Agile approach with all its concentration on sprints, iterations, and open dialogue with the client comes equipped with the ability to speed up product testing and attribute product functionality to user needs better while at the same time being able to track environmental impacts in real-time.

Theoretical research findings suggest that the iterative feature of Agile can be applied efficiently in product development so that development can be conducted with sustainability as the focus. The QILCA model has the capability of concurrent assessment of environmental optimisation and quality and innovation needs, a primary area of differentiation from other ecodesign support tools. Basic model abilities, i.e., mapping of product characteristics to Q and I requirements and to the environmental impact indicator (LCA), make it possible for early recognition of potential design improvement opportunities. These outcomes indicate that the approach set forth in this work can be applied to lead firms towards sustainable performance without reducing competitiveness—an ever-growing challenge with mass customization-industry segments.

The proposed QILCA model can ignite a broader discussion on applying Agile principles from IT departments to product engineering and manufacturing, potentially ushering in a new era of product design software for Industry 4.0 (I4.0) and 5.0 (I5.0). Its indicators and cyclic trends offer a foundation for industry case studies and experimental research, enabling the calibration of criterion weights, validation of applicability, and cross-industry transferability. Moreover, the model opens pathways for integration with digital twins, multi-criteria decision support systems, and quality management system advancements that could yield measurable gains in future product optimization.

Conventional Life Cycle Assessment (LCA) process can be supported by integrating quality and innovation drivers at the start of the product design cycle into environmental study integration with recursive Agile-type design researching clients' technical and usability requirements together. This extension entails the incorporation of quality attributes (functionality, ergonomics, reliability, and durability) into core LCA indicators, and innovation attributes such as technological innovation, modularity, information system compatibility, and automation potential.

The envisioned QILCA model is a seminal extension of traditional LCA practice with the introduction of quality and innovation dimensions and hence filling a gap in the literature constructed in scientific literature (Balcioglu et al., 2025; B. Dong et al., 2017). The LCA had previously focused on the overall environmental burden of a product along the product life cycle (Finkbeiner et al., 2006), whereas the new approach enables the double evaluation of quality and innovativeness as design strategic product dimensions. The iterative process of the model, having been tried and proven under Agile protocols, identifies a need for faster product validation along with better correlation of design parameters to customer needs (Sadia et al., 2021). Studies show that combining the different dimensions of measurement, i.e., quality, innovation, and environmental dimensions, allows for more stringent regulation of rules for

sustainable development with an emphasis on optimizing products in terms of function and price (Gajdzik, Siwiec et al., 2024).

In the era of sustainable consumption, customers are increasingly aware of products that reduce their environmental impact after purchase. Research by Gajdzik et al. (2023) confirmed this pattern over a long period of time (compared across decades). However, in the manufacturer market, the concept of a new model QILCA could be useful because it would accelerate the transfer of knowledge across sectors (Sroka et al., 2014).

Agile components integrated into the QILCA model align with increasing use of agile project management in sectors other than IT (Bai et al., 2018; Falco, Robiolo, 2021). Scrum and other Agile methods can maintain iterative and cyclic iteration, ongoing testing, and product changes that morph to facilitate rapid response toward changing market and customer needs, as disseminated by Schwaber and Sutherland (2017). Empirical data of Bhagwat et al. (2021) and Camañes et al. (2024) testify that iterated design cycles and the use of digital tools in eco-designing can practically reduce environmental footprint and time-to-market. Its use in product design under LCA thus facilitates, with ongoing environmental influence tracking and optimization, inducing innovation activity and improving project risk management (Radhakrishnan, Koumaditis, 2020; Wysocki, 2019).

Literature review also shows the application of the QILCA model to mass product customization and Industry 4.0 where emphasis on elastic design processes and directing environmental intelligence into decision-making increases (Gajdzik, Jaciow et al., 2024; Kumar, 2007). Quality and innovation requirements, such as reliability, ergonomics, modularity, or inter-operability with digital technology (Ekmekci, Nebati, 2019; Luo et al., 2025), are inevitable factors of the building of competitive advantage, and their coordination with LCA outcomes exceeds the challenges facing sustainable development. Its adoption is capable of propelling value-added product creation at low environmental effort, as facilitated by TRIZ innovation and product lifecycle management research (Livotov, Petrov, 2023). The QILCA model thus represents a move towards end-to-end assessment tools with customer, business, and environmental concerns.

The results of the research are in line with macro-level studies of embedding LCA methodology into quality management theory and innovation theory by stressing the importance of systemic product design strategy in the Industry 4.0 (I4.0) environment. Following the product life cycle theory of Finkbeiner et al. (2006), analysis of environmental impacts should be conducted during the design phase. However, these analyses are primarily retrograde exercises with little to give back to product design. QILCA methodology, on the other hand, is targeted from an early point in the development cycles, bridging models of quality management (TQM, ISO/IEC 25010) and modes of innovation management (TRIZ) to environmental considerations according to quality management system guidelines and sustainable product development guidelines (Jiao, Chen, 2006; Livotov, Petrov, 2023; Rahman, Alam, 2022). Theoretical framework makes sure that balancing at the same time the quality and

innovation dimensions have the highest potential for gaining competitive advantage with minimal environmental threat (Gajdzik, Wolniak, 2022b).

Theoretical excellence of the QILCA model is more than the jurisdiction of single measurement approach, offering an eclectic decision-support system in product design. This method is based on MCDM-logic to enable compromise of each other conflicting quality, innovation, and environmental demands (Mu, Pereyra-Rojas, 2017; Siwiec, Pacana, 2024b; Pacana, Siwiec, 2024). Weighting and ranking logic-based QILCA-defined criteria enable open project management of multicomplex projects in precision-based industries like automotive, aviation, and electronics (Gajdzik, Burchart-Korol, 2011; Gajdzik, Siwiec et al., 2024; Siwiec, Gajdzik, Pacana et al., 2025). In addition, the model includes customer value (Voice of Customer) as a philosophy and thus user expectation is a design starting point such that new but eco-friendly products are created (Barravecchia et al., 2023).

Paper conclusions are that QILCA model is open innovation compliant, with the end aim being to include customers and stakeholders directly in product innovation and development. In being part of the future stages of the product design process, the model positions outside partners as co-creators of innovation. This approach embodies the open innovation concept, where knowledge and ideas outside a company are a resource and may be a counterbalance to market mismatch risks (Asad et al., 2023; Azhar Mohd Harif et al., 2022; Han et al., 2021). Ecological transformation through open innovations, however, requires a holistic approach and government support (Burchart, Przytuła, 2024, 2025; Zhou, Zhang et al., 2022, Zhou, Zhang et al., 2025). A holistic approach to eco-innovations is to view them as part of a broader, complex system rather than as isolated solutions, allowing for consideration of the entire product life cycle, its relationship with environmental and social impacts, and integration with existing processes to achieve sustainability in a broader context (Zhou, Richardson-Barlow et al., 2025).

The cyclical nature of QILCA also mirrors openness in the innovation process. The regular reviews, retrospectives, and sprints permit ongoing uptake of new ideas, quick prototyping, and continuously constructed products from continuously changing demands in the markets. The activities permit ongoing sharing of knowledge among organizations and the ecosystem, again mirroring openness of organizational boundaries. The model thus mirrors open innovation's collaborative, knowledge-sharing culture.

QILCA also is open innovation friendly because it unites environment drivers, quality drivers, and innovation drivers. Sustainable innovation is more a matter of coordination across large networks of partners such as technology providers, research centers, NGOs, and authorities. The model creates a formal mechanism of coordination so that product innovation responds to both customer demand and environment and society demand. The same multi-dimension also creates legitimacy and, in market, marketability of innovations.

The scalability and transferability of QILCA enable it to effectively govern open innovation ecosystems. Because the framework can be applied across diverse industries, including Industry 4.0 and mass customization environments, it supports the replication and dissemination of best practices. By enabling collaborative platforms that enhance competitiveness through continuous and integrated improvement processes, the model promotes both knowledge exchange and organizational learning. Consequently, QILCA strengthens innovation networks that extend across organizational boundaries.

5. Conclusion

Our proposed integration of Agile principles into product design and Life Cycle Assessment (LCA) offers significant value for both clients and businesses by enhancing flexibility, responsiveness, and sustainability-oriented decision-making. Nevertheless, the Agile framework is not universally applicable to all product improvement and customization processes. Certain products, particularly those characterized by rigid regulatory requirements, highly standardized production systems, or limited design flexibility, may not benefit from iterative Agile methodologies. In such cases, traditional development approaches may provide greater stability and predictability. Therefore, the successful implementation of QILCA depends on aligning Agile practices with the specific technical, organizational, and market conditions of the product development environment.

Through the proposed QILCA framework within an Agile approach, the authors hope to initiate a discussion on the possibilities of applying Agile to product improvement, but by using the QLCA model, i.e., a strong integration of LCA with the quality criteria of the improved product, which must incorporate features of innovativeness (I). Ultimately, both categories of improvement must be strongly correlated with either a positive environmental impact of the product or a reduced environmental burden compared to the previous product (the criterion of improved environmental performance).

With this paper, the authors invite scientific and business discussion on the feasibility of applying the Agile approach, beyond IT products (the IT market), to the improvement of products across their entire LCA.

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PROPOSALS OF THE INSURED REGARDING THE DIRECTIONS OF SOCIAL SECURITY REGULATIONS IN POLAND

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Purpose: Reforming social insurance systems is a permanent process worldwide. One of the fundamental objectives of these reforms is to balance revenues and expenditures within the system. In Poland, the system has been operating at a deficit since 1987, and the reforms implemented so far have not improved its financial condition.
The aim of this article is to present the financial necessity of reforming the social insurance system in Poland, as well as the changes to this system proposed by its participants (the insured persons).
Design/methodology/approach: The study employed methods of document analysis, economic analysis using a financial efficiency indicator, and a survey.
Findings: The theoretical analysis and the conducted research indicate that reforming the Polish social insurance system is necessary. The recommended directions of these changes include, in the pension insurance and disability insurance systems, increasing the level of benefits through state subsidies, while in sickness insurance the proposed changes involve either the standardization of benefits or increasing benefit levels through higher contribution rates. It is also necessary to continue monitoring the opinions of active participants in the system (persons paying social insurance contributions) in order to identify optimal solutions for reducing the deficit of the Social Insurance Fund (FUS) and meeting public expectations.
Research limitations/implications: A limitation that had some impact on the study results was the respondents' avoidance of giving specific answers to certain questions, which, in the author's opinion, resulted from insufficient knowledge of the social insurance system.
Practical implications: The study identified the scope of respondents' expectations regarding possible future changes in the functioning of the system. In conclusion, the proposed changes would reduce the FUS deficit and could potentially increase the level of benefits paid.
Originality/value: The article presents the opinions of insured (participants in the system) regarding the scope of necessary changes to the Polish social insurance system. The article is primarily addressed to public authorities responsible for public finances, as well as specialists in public finance management and social policy development.
Keywords: social insurance reform, pension system, disability insurance system, sickness insurance system, parametric changes.
Category of the paper: General review.

1. Introduction

The social insurance system is one of the fundamental elements of state financial management. Its functioning is the subject of research and analysis conducted by specialists in social policy and public finance management. The reform of social insurance itself is a permanent process, carried out over decades in every country in the world. The need to reform this system results from the dynamics of each country's socio-economic policy development, as well as demographic changes such as population aging, declining birth rates, and increasing life expectancy. Poland is no exception in this regard; however, additional problems exist in our country, including errors in the pension system and omissions such as the lack of reform in disability and sickness insurance, which further deepen the financial problems of social insurance.

The article presents the scale of the deficit of the Social Insurance Fund in recent years, as well as forecasts of these shortages in the coming years. The directions of potential measures aimed at improving the functioning of the system are defined on the basis of proposals made by respondents who are active participants in the system (individuals paying contributions).

The central thesis of the study was that the chronic financial deficit of the social insurance system should be addressed through carefully designed parametric adjustments, as suggested, among others, by the insured population.

This thesis implied the need to find answers in the conducted research to the following questions:

- What is the scale of the financial deficit of the Social Insurance Fund?
- What measures are necessary to balance revenues and expenditures in pension insurance?
- What measures are necessary to balance revenues and expenditures in disability insurance?
- What measures are necessary to balance revenues and expenditures in sickness insurance?

A survey questionnaire was used as the research tool to find answers to the above questions.

2. Research Methodology

The study employed document analysis methods, economic analysis using a financial efficiency indicator, and a survey questionnaire. The issue of paying insurance contributions has been discussed in Polish subject literature for many years. Based on these considerations,

and for the purpose of examining the financial efficiency of the social insurance system, a financial efficiency indicator was developed and applied in the data analysis.

In social insurance theory, the financing of systems is based on actuarial calculations, which involve applying the principle that the incurred inputs (contributions) should balance or exceed the resulting outputs, namely the benefits paid (Bezpieczeństwo, 1997, p. 37).

To achieve such a state, it is necessary to balance revenues and expenditures within the system, that is, to create a situation in which the discounted value of all contributions paid into the system over all months of insurance coverage (within a given year), increased by any reserves (or the system's initial debt), is equal to the present discounted value of all benefits paid out.

Treating insurance contributions as inputs (N) and paid benefits as outputs (S), a simple relationship can be formulated to determine whether the system is efficient:

- for $Sk \geq Sw + K$ $f(Se) \geq 1$ the system is efficient,
- for $Sk < Sw + K$ $f(Se) < 1$ the system is inefficient.

where:

f(Se) – financial efficiency of the social insurance system,

Sk – social insurance contributions,

Sw – benefits paid from the system,

K – administrative costs.

Taking these relationships into account, it is possible to define the gross financial efficiency indicator of the system and the net financial efficiency indicator of the system.

$$WEFS_b = \frac{\sum \text{contributions}}{\sum \text{benefits+costs}} \quad (1)$$

The gross financial efficiency indicator shows to what extent contributions cover the benefits paid from a given system or subsystem, as well as the administrative costs incurred in managing that system

$$WEFS_n = \frac{\sum \text{contributions}}{\sum \text{benefits}} \quad (2)$$

The analysis used the net financial efficiency indicator, which shows the extent to which contributions cover the benefits paid from a given system (Garbiec, 2013, pp. 24-30), without taking into account costs, which in Poland are fixed and determined by statutory regulations.

A study conducted in 2025 on the scope of knowledge and lack of knowledge concerning the Polish social and health insurance system involved a group of 502 active participants in the system (insured persons paying social insurance contributions). The study concerned economically active individuals, i.e. persons employed under employment contracts, civil-law contracts (contracts of mandate, service contracts, contracts for specific work), as well as self-employed individuals conducting non-agricultural business activity and cooperating persons (family members of such individuals).

The survey questionnaire included questions concerning the range of potential proposals by respondents regarding parametric changes in the existing pension, disability, and sickness insurance system. The study did not include accident insurance, which is also part of the Polish social insurance system, due to its long-term financial efficiency remaining above the level of 1.

3. Results

Analysis of Respondents' Preferences Concerning Parametric Reforms

The conducted research was purposeful in nature, and the respondents consisted exclusively of economically active individuals, i.e. persons obliged to pay social insurance contributions. Among the questions asked were also issues not included in this article, concerning expectations towards the institution managing the system (ZUS) and the respondents' level of knowledge.

The survey questions presented below concerned parametric changes in the pension system, disability pension system, and sickness insurance system.

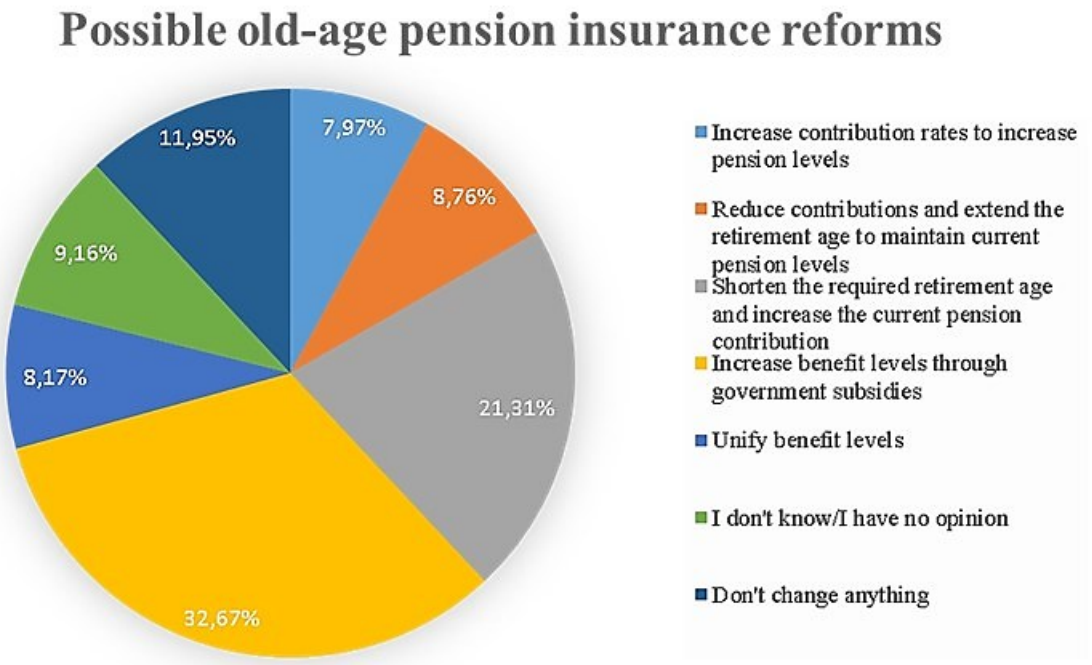

Figure 1. Potential Changes in the Pension System.

Source: author's own study based on the conducted survey.

The conducted study indicates that insured individuals in the Polish pension system expect an increase in benefit amounts either through state subsidies (32.67%) or through earlier eligibility for benefits combined with higher contribution rates (21.31%). The increased role of the state proposed by respondents is inconsistent with the principles of the reform introduced

in 1999. On the other hand, a rational solution proposed by respondents would be to increase contribution rates as compensation for earlier retirement. Only a small number of insured individuals would prefer a uniform benefit amount for everyone (8.17%), while only slightly more respondents oppose reforming the system (11.95%).

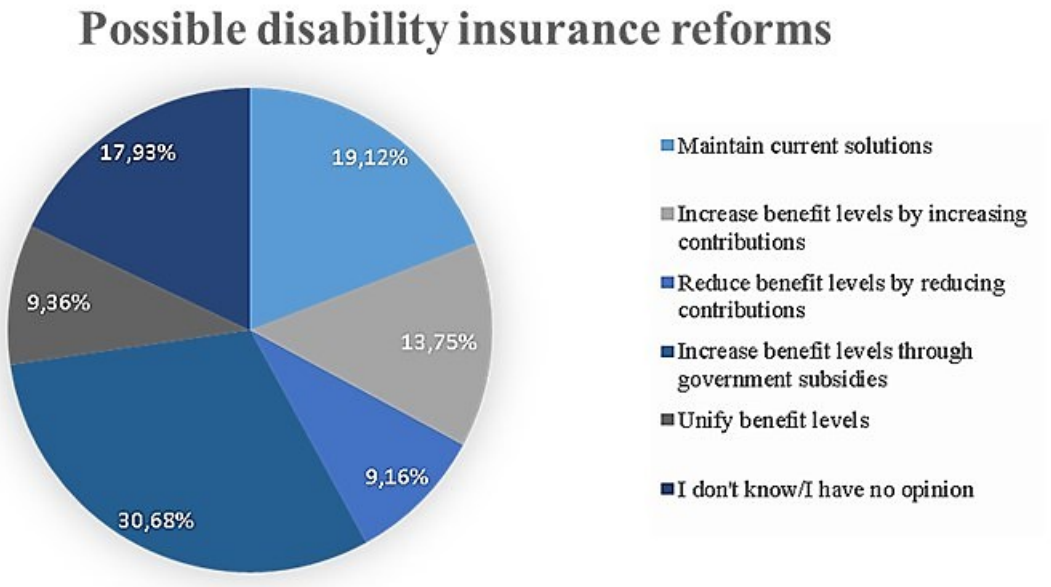

Figure 2. Potential Changes in the Disability Pension System.

Source: author's own study based on the conducted survey.

With regard to the potential reform of the disability pension system, insured individuals expect an increase in benefit amounts through state subsidies (30.68%), alternatively the maintenance of the current solutions (18.12%), or they express no opinion on the matter (17.93%). Such a distribution of respondents' answers indicates that this type of social insurance is not of great interest to them. Only a small proportion of respondents (13.76%) expect higher benefits through an increase in contribution rates. Solutions involving the standardization of benefit amounts or their reduction together with lower contribution rates were chosen by less than 10% of respondents.

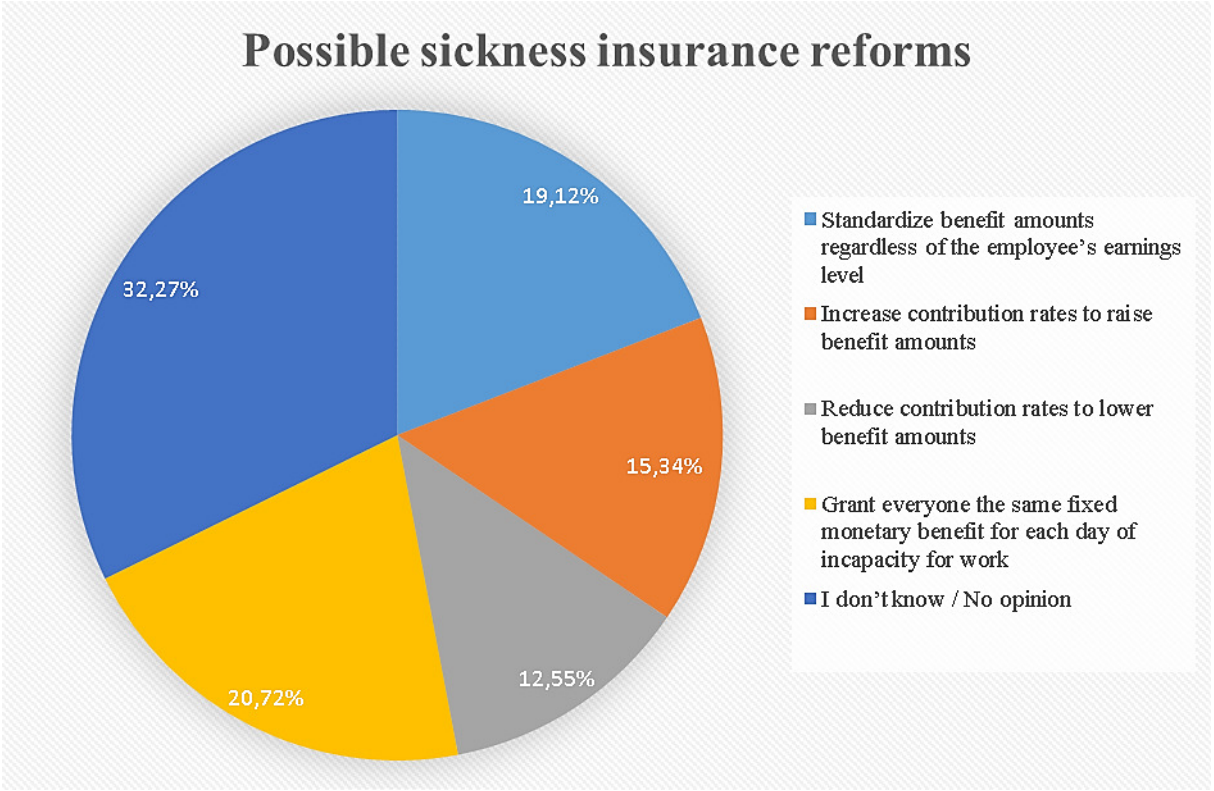

Figure 3. Potential changes in the disease system.

Source: own elaboration based on the conducted survey.

The conducted study shows that insured individuals tend to avoid providing an answer (32.27%), while the most common proposed reform option for this type of social insurance is the standardization of benefit levels (20.72%) or increasing benefits through higher contributions (19.12%). A reduction in benefit levels accompanied by a reduction in contribution levels was indicated by 15.12% of respondents. The least frequently selected option was increasing benefits through higher state subsidies (12.55%).

The reluctance to express opinions on changes to sickness insurance is attributable to a relatively low level of knowledge about how this insurance system operates. An analysis of insured persons' knowledge of the system is presented in a separate article.

4. Discussion

Assessment of the Financial Situation of the Social Insurance Fund

The discussion on deficits (financial efficiency) in the Social Insurance Fund (FUS) in Poland has been ongoing since 1988. The main argument for implementing systemic reform of the Polish social insurance system in 1999 was the FUS deficit, which before the reform ranged from 10% to 14%. Several decades after the reform, this deficit still ranges from 13% to 25%, and forecasts for the coming years remain around 18%.

Table 1.
Financial efficiency of Social Insurance Fund

Year	Contributions and related revenues (PLN million)	Benefit expenditure (PLN million)	Financial efficiency of Social Insurance Fund
2020-2024			
2020	197 231	260 463	0,7572
2021	228 616	276 205	0,8277
2022	261 438	299 967	0,8715
2023	301 352	352 083	0.8559
2024	346 979	406 194	0.8542
Forecast for 2025-2030 [1]			
2026	383 391	462 684	0,8286
2027	397 834	483 532	0,8227
2028	412 455	500 378	0.8242
2029	427 834	516 993	0,8275
2030	443 439	532 463	0,8328

[1] intermediate scenario between the pessimistic and optimistic variants.

Source: own elaboration based on ZUS data: Key information on social insurance 2021–2025 *and* Forecast of revenues and expenditures of the Social Insurance Fund for 2026–2030.

The reform implemented in 1999 did not change the functioning of the disability pension system, and changes in the sickness insurance system were only symbolic. The systemic and parametric changes introduced in the pension system did not reduce the FUS deficit; instead, they only introduced a liberal pension system that does not guarantee a minimum standard of living for a significant group of insured individuals. The need to undertake further actions to improve the financial efficiency of social insurance in Poland is justified based on the analysis of efficiency indicators. In analyzing the functioning of the social insurance system, not only financial arguments are important, but also the potential expectations and proposals of system participants (insured persons within the system).

In foreign academic publications, the issue of reforming social insurance is systematically addressed. Despite their diversity, countries in all regions of the world faced many common challenges in the field of social security in the years 2023-2025. These include coping with demographic change and the associated ageing of society, closing gaps in insurance systems, ensuring lifelong protection, and adapting to changing labour markets. Many countries have sought to meet these challenges through a broad range of legal reforms, expanding regulatory provisions. Other countries have focused on optimizing the administration and management of existing programs. In recent years, extensive reforms of social security systems have been carried out worldwide, as governments seek to find a balance between financial stability and the goal of providing inclusive and adequate support for diverse social groups (Global overview, 2025).

Social insurance faces a long-term financial problem. However, it is difficult to reach a broad consensus on which specific reforms should be adopted. Many reform proposals aim at much more than merely addressing the issue of long-term actuarial imbalance in social insurance. One reason why it is difficult to achieve consensus on reforms is that potential reformers differ in the degree of attention they assign to particular objectives. Although

actuarial balance in social insurance could be relatively easily restored by an immediate increase in contribution rates, the need for reform creates an opportunity to reassess the program and consider more fundamental changes (Triest, 1997).

Leaders in analyses and proposals for improving the financial situation of social insurance are the United States, where even a guide for analyzing social insurance reforms has been developed. This handbook states, among other things, that abandoning the self-financing concept of social insurance would lead to the worst political scenarios, while simultaneously undermining mechanisms of financial discipline as well as the reliability and security of benefits (Munnell, 2025). However, as Mark J. Warshawsky noted, in the United States social security reform is no longer in vogue, even on the right. Across the entire political spectrum, ignoring the financial challenges and design flaws of the program is now regarded as political astuteness (Warshawsky, 2026). In the U.S., the main cause of the financing gap in social security is increasing life expectancy. To partially address this funding gap, raising the retirement age has been proposed. Andrew G. Biggs and John Shoven suggested increasing the retirement age as a way to reduce debt, and the proposed reform has the advantage of being linked to longer life expectancy, which makes it more understandable to the public (Biggs, Shoven, 2025).

Meanwhile, in recent years in the United Kingdom, it has been observed in the field of social security finance reform that policymakers seeking to reform welfare systems often face a fundamental problem of reconciling reductions in social spending with the political challenges of implementing unpopular reforms. One proposed approach to reform there is transforming existing institutions so that they serve new purposes (Koch, 2021). At the same time, Karl Hinrichs stated that over the past 30 years all European Union member states have reformed their pension systems. In response to ongoing and intensifying population ageing, measures are being taken to limit future contribution increases, improve the system dependency ratio, reduce benefit levels, and/or inject tax revenues or other financial resources into the system. The analysis of reforms shows a limited range of adjustment options, and specific measures must be tailored to country-specific institutional conditions. Pension reforms focused on long-term financial stability may increase the risk of poverty among the elderly, thereby undermining the main objective of pension systems (Hinrichs, 2021). s Javier Díaz-Giménez and Julián Díaz-Saavedra noted, one of the main causes of the lack of stability of future pensions in many European countries is the failure to adapt to long-term demographic trends. Moreover, reforms aimed at addressing financial problems may provide an opportunity to improve the design of pension systems. However, such reforms are sometimes rejected when they lead to significant short-term losses in pension income (Díaz-Giménez, Díaz-Saavedra, 2025). According to Sarah Steele, Milagros Ruiz, Matthew Parbst, and David Stuckler, governments implementing reforms aimed at ensuring financial stability—such as raising the retirement age, reducing benefits, and shifting to defined-contribution systems—often overlook their psychological and social consequences. Pension insecurity is associated with increased stress, anxiety,

and depression, as well as greater social isolation, particularly among vulnerable groups, including physically demanding workers, low-income employees, and individuals with pre-existing health conditions (Steele et al.).According to Jean Hendriks and Sefane Cetin, many countries have implemented a range of pension reforms in response to the challenges of population ageing. These reforms typically involve a trade-off between "refinancing" (i.e., increasing contributions) and "retrenchment" (i.e., reducing benefits). Their study found a divergence between projected pension benefits and optimal benefit levels in many EU countries (Hendriks, Cetin, 2026). Research by Huixin Bi and Sarah Zubairy shows, among other things, that structural pension reforms motivated by concerns over long-term sustainability often involve extended implementation periods (Bi, Zubairy, 2023). Importantly, Erik Hernæs, Simen Markussen, and John Piggott (based on the reform implemented in Norway in 2011) found that properly designed pension reforms must take into account the interaction between pension schemes and disability insurance programs (Hernæs et al., 2024).

In the area of disability insurance, Zachary A. Morris, in his 2024 publication, presented assessments of the accessibility and level of disability benefits in the United States (Morris, 2024). Meanwhile, in research on sickness and disability insurance, Kaarina Reini and Jan Saarela presented sickness benefits paid in Finland as an indicator of temporary poor health, but in their view this indicator is also associated with an increased risk of receiving a disability pension (Klein et al., 2021).

With regard to sickness insurance itself, recent international publications have primarily addressed the issue of sick leave. E.A. Karlsson, J.L. Sandqvist, I. Seing, and Ch. Ståhl presented efforts undertaken in Sweden to reduce the number of sick leaves, which led to a stronger link between social security and work, as well as the identification of attempts to simulate poor health (Karlsson et al., 2022). Meanwhile, M. Palme and M. Persson found that all European countries have some form of mandatory insurance against income loss during incapacity for work. Insurance systems vary significantly across countries both in measurable aspects (such as wage levels) and in non-measurable features concerning the actual implementation of programs (Palme, Persson, 2020). To positively change the narrative around sick leave, norms and their impact on studied individuals must be recognized (Moldvik et al., 2021). Moreover, social welfare specialists must determine what is involved in decision-making processes, for example regarding eligibility for sickness benefits (Karlsson et al., 2021). Other researchers, however, have pointed out that long-term sick leave is a complex phenomenon. Medical and non-medical factors may delay return to work, which makes assessment of work capacity complicated (Tikka et al., 2022).

In Polish literature on the financing of social insurance, it has been noted, among other things, that public authorities require financial resources necessary to carry out their tasks (Bąkowski, Lewkowicz-Grzegorczyk, 2024, p. 152; Owsiak, 2005). According to Kamila Bielawska, the assessment of financial adequacy and stability is well developed and constitutes a certain standard. However, the area related to the modernization of social insurance—

i.e., adapting it to changing demographic and economic conditions—remains a challenge. Too little attention is given to the assessment of gender equality, the scale of redistribution, transparency, and the credibility of information on social insurance (Bielawska, 2021, p. 189). The implementation of the 1999 reform did not protect contributors and insured persons from numerous subsequent changes introduced by the legislature. The assumptions of the reform concerning the transformation of the system from a pay-as-you-go model to a funded one have been gradually reversed. Such a situation may improve the state's current finances, but in the long term it may have an adverse impact on the implemented pension system (Chrzanowska, 2017, pp. 29-30). The need to reform the pension system in Poland was also indicated by Joanna Niżnik. In her view, after years of functioning in the new formula, the growing deficit of the pension system and difficulties in its financing prompted the government to initiate discussions and subsequently legislative actions aimed at introducing necessary adjustments. Whether these changes will be sufficient will depend on the country's economic and demographic situation (Niżnik, 2011, pp. 333, 346). Meanwhile, the financial efficiency of the social insurance system in Poland, the inconsistency of its structure, and the lack of a unified guiding concept imply the need for systemic and parametric changes. Currently, social risks covered by the Polish social insurance system are protected in a non-uniform manner, and the types of benefits paid are incoherently designed and calculated using different methods (Garbiec, 2021, pp. 43-44).

5. Summary

The reform of the social insurance system in Poland is necessary not only for financial reasons (the deficit of the Social Insurance Fund) but also for social reasons, i.e. the opinions of insured individuals in this regard. In recent years, this deficit, expressed by the net efficiency ratio, has ranged from 0.8715 to 0.7572, with the expected value equal to 1. In the coming years, it will still remain in deficit, reaching values between 0.8227 and 0.8328. Before the introduction of reforms, the deficit ranged from 0.7859 to 0.9519 (Garbiec, 2013, p. 36).

A study of active participants in the system (individuals paying contributions) regarding proposed changes in the social insurance system showed that these changes should be as follows:

- in old-age pension insurance, insured individuals expect an increase in benefits either through state subsidies or earlier entitlement to benefits, combined with a simultaneous increase in contribution levels.
- in disability insurance, insured individuals primarily expect an increase in benefits through state subsidies or the maintenance of current arrangements.

- in sickness insurance, insured individuals tend to avoid indicating a specific direction of change; the most common reform option is the standardization of benefit levels or increasing benefits through higher contribution rates.

The above conclusions, based on the opinions of insured individuals, express their expectations and preferences (an increase in benefit amounts, state subsidies for benefits), but also indicate possible directions for potential changes that could serve as solutions to reduce the deficit of the Social Insurance Institution (ZUS), such as increasing the level of contributions.

The study shows that reforming the Polish social insurance system is necessary and the indicated directions of change should be further analyzed by specialists before ultimately reaching decision-makers (politicians).

It is also necessary for specialists in public finance management and social policy to continue monitoring the expectations of active participants in the system (individuals paying social insurance contributions) in order to find optimal solutions to the problem of the Social Insurance Fund deficit, both in financial and social terms.

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SUSTAINABLE ENTREPRENEURSHIP AS A DETERMINANT OF THE DEVELOPMENT OF SUSTAINABLE LOGISTICS: IN ITALY AND POLAND

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Purpose: The purpose of this paper is to empirically examine whether sustainable entrepreneurship influences sustainable logistics development in Italy and Poland across economic, social, and environmental dimensions.
Design/methodology/approach: The study uses annual data for Italy and Poland from 2008 to 2023, obtained from the Eurostat database. The empirical analysis applies OLS and SUR models with lagged variables to capture dynamic interdependencies between the analysed dimensions.
Findings: The results confirm that sustainable entrepreneurship significantly influences the development of sustainable logistics, although the strength and dynamics of this relationship differ between Italy and Poland. In Italy, the impact of sustainable entrepreneurship on sustainable logistics is stronger and more immediate, while in Poland the effects are more delayed and temporally dispersed. The findings also indicate significant interdependencies among the pillars of sustainable logistics, particularly in Poland, which justifies the use of SUR models. Furthermore, the study confirms the importance of ESG-oriented investments, green innovation diffusion, and institutional pressures as mechanisms supporting the transformation of logistics systems supporting sustainable logistics transformation.
Research limitations/implications: The main limitations of the study are the relatively small sample size and the inclusion of only two countries. However, the study offers a methodological framework for future comparative analyses involving a wider range of economies and longer time horizons.
Practical implications: The findings may support policymakers and enterprises in designing sustainability-oriented logistics and economic strategies.
Social implications: The shift towards sustainable logistics may help reduce environmental pressure, improve resource efficiency, and support sustainable development objectives.
Originality/value: The originality of the study lies in integrating sustainable entrepreneurship and sustainable logistics within a dynamic empirical framework that incorporates time lags and

systemic interdependencies. The study contributes to the literature through a comparative analysis of Italy and Poland using synthetic indicators and SUR modelling.
Keywords: ESG, green logistics, supply-chain transformation, institutional pressures, SUR modelling, comparative analysis.
Category of the paper: Research paper.

1. Introduction

Modern economies face growing pressure to implement sustainable development principles, which is reflected in both public policies and corporate strategies. The logistics sector, in particular, as a key element of economic systems, plays a significant role in shaping the impact of economic activity on the natural environment and society (Koray et al., 2025; Bartosiewicz et al., 2025). The intensity of transport processes, the high emissions, and the growing demand for efficient supply chains make the transformation of logistics into sustainability one of the main challenges of the modern economy (Sun et al., 2025; Bugarčić et al., 2023).

At the same time, the concept of sustainable entrepreneurship, which involves the integration of economic, social, and environmental goals in the operations of businesses, is undergoing dynamic development (Odeyemi et al., 2024). Companies are increasingly implementing strategies based on ESG principles and taking steps to reduce their negative impact on the environment while seeking new sources of competitive advantage (Rosário et al., 2022). In this context, a crucial question arises about the role of sustainable entrepreneurship as a potential driver of transformation for entire sectors of the economy, including the logistics sector.

Research to date has focused primarily on analysing individual aspects of the phenomena discussed. On the one hand, studies on sustainable logistics are being developed that include, among others, green supply chains, emissions reduction, and transport efficiency, while on the other hand, sustainable entrepreneurship is being analysed in the context of innovation, social responsibility, and institutional regulations. However, attempts to comprehensively address the relationships between these two areas, especially at the macroeconomic and sectoral levels, are much less common.

The existing literature points to potential links between the implementation of sustainable practices in enterprises and changes in the functioning of supply chains, but empirical studies that would clearly determine the strength, direction, and dynamics of these relationships are still lacking. A particularly noticeable research gap is in quantitative analyses that simultaneously consider the multidimensional nature of sustainable development, the time lags in the impact of the analysed phenomena, and the structural differences between countries with different economic models.

The interdependencies between the individual pillars of sustainable logistics and their response to changes in the level of sustainable entrepreneurship also remain insufficiently understood. Previous research rarely considers the systemic nature of these relationships, which limits the ability to fully understand transformation mechanisms in the logistics sector (Tutar et al., 2026; Shabbir, 2023).

In response to identified research gaps, this article attempts to empirically verify the impact of sustainable entrepreneurship on the development of sustainable logistics in a comparative approach for two European countries, Italy and Poland. The research approach, based on dynamic analysis and the use of econometric models that account for time lags and interdependencies between variables, allows for an in-depth identification of the mechanisms of influence and structural differences between the analysed economies.

This article is empirical in nature and is based on the analysis of annual data for Poland and Italy from 2008 to 2023, sourced from the Eurostat database. The study uses proprietary synthetic indicators: the Sustainable Entrepreneurship Index (SE) and the Sustainable Logistics Index (SL), constructed based on diagnostic variables assigned to the three pillars of sustainable development: economic, social, and environmental. The research procedure includes trend analysis and descriptive statistics, correlation analysis, and econometric modelling.

In particular, linear regression models estimated by ordinary least squares (OLS) were used to identify the impact of current and lagged SE values on SL, thus capturing the dynamic nature of the relationships analysed. Furthermore, SUR (seemingly unrelated regressions) models were used, which enable the simultaneous analysis of individual pillars of sustainable logistics and account for their interconnections.

This research approach allows for a comprehensive analysis of the relationship between sustainable entrepreneurship and sustainable logistics, from both a static and a dynamic and systemic perspective. This article contributes to the literature by providing quantitative empirical evidence and developing a methodological approach that accounts for time lags and interdependencies between the analysed phenomena.

2. Literature Review

Sustainable entrepreneurship and sustainable logistics are part of a broader stream of research on sustainable development, the theoretical foundations of which stem from the concept of three pillars (economic, social, and environmental), known as the triple bottom line (Koray et al., 2025). The literature emphasises that sustainable economic development requires the simultaneous consideration of economic efficiency, social responsibility, and the reduction of negative environmental impact (Mezentseva et al., 2024; Andersson et al., 2022; Jindal, 2025).

Sustainable entrepreneurship is most often defined as business activities that integrate economic goals with social and environmental objectives, creating value for both owners and broader stakeholders (Rosário, Figueiredo, 2024; Yasir et al., 2023). Theoretically, this concept develops at the intersection of entrepreneurship theory, stakeholder theory, and the resource-based view (RBV) (Haryanto et al., 2026; Agrawal et al., 2025). According to this approach, companies that effectively implement sustainable strategies build competitive advantages through the development of unique resources and competencies, such as ecological innovation and the ability to manage social relationships (Rosário et al., 2022; Kucharski et al., 2025).

An important complement to this is institutional theory, which indicates that companies' sustainability efforts are largely determined by the regulatory environment, social norms, and stakeholder pressure. In this context, implementing ESG (Environmental, Social, Governance) practices can be both a result of regulatory pressure and an element of a strategy for building reputation and social legitimacy (Kim, Kim, 2025; Chipimo et al., 2025; Haryanto et al., 2026).

Sustainable logistics, in turn, expands on classic supply chain management concepts and focusses on minimising the negative impact of logistics processes on the environment while maintaining operational efficiency and service quality (Ferraro et al., 2026). The literature indicates that logistics plays a key role in achieving sustainable development goals, as it accounts for a significant portion of greenhouse gas emissions and resource consumption (Grechan et al., 2022). In this context, concepts such as green logistics, reverse logistics, and circular supply chains are being developed, including transportation optimisation, waste reduction, and resource reuse (Waqar et al., 2025; Bugarčić et al., 2023; Ferraro et al., 2026).

The relationship between sustainable entrepreneurship and sustainable logistics is relatively less quantitatively analysed, but existing research indicates that companies that implement sustainable strategies are more likely to invest in environmentally friendly logistics solutions and introduce process innovations that reduce environmental impact (Boonnual et al., 2025; Jayarathna et al., 2024). The literature also emphasises the importance of delayed effects: Transformation of business models and supply chains takes time, meaning that the impact of companies' actions on the logistics sector may only become apparent in the medium or long term (Palkina, 2022; Sreenivasan, Suresh, 2023; Jayarathna et al., 2024).

An important theoretical strand justifying the use of dynamic models in this study is the evolutionary approach and path dependence theory. According to this approach, economic processes are cumulative and depend on previous decisions, which means that the current level of logistics development is largely determined by previous investments and strategies of companies (Rakyta et al., 2022; Sonar et al., 2024; Duzgun, Atay, 2026).

Furthermore, the literature indicates the existence of interdependence between the individual pillars of sustainable development, which is reflected in system concepts and a holistic approach (Tutar et al., 2026; Shabbir, 2023). According to this approach, changes in one area (e.g., economic) can have consequences in others (social and environmental),

justifying the use of methods such as SUR models, which allow for the analysis of interdependent equations.

The literature discussed above suggests that sustainable entrepreneurship may influence sustainable logistics through several interconnected mechanisms. Recent studies indicate that ESG-oriented investments increasingly stimulate the adoption of green supply chain practices, low-emission transport systems, and environmentally efficient logistics infrastructure (Saeed et al., 2018; Xu et al., 2023). Institutional pressures and stakeholder expectations have also been identified as important drivers of green innovation diffusion and sustainable supply chain integration (Ning et al., 2021; Zhang et al., 2025). Previous studies have also emphasised the importance of institutional and financial mechanisms in supporting sustainability-oriented transformation processes and ESG implementation dynamics in European and transition economies (Olgić Draženović et al., 2023).

As these transformation processes are cumulative and time-dependent, the effects of sustainable entrepreneurship on sustainable logistics may emerge with significant time lags and vary across countries depending on institutional and structural conditions. Analysing the relationship between sustainable entrepreneurship and sustainable logistics therefore requires a dynamic, systemic research approach.

3. Research Methodology

3.1. Main idea and research problem

The main idea of this article is to analyse the extent to which sustainable entrepreneurship at the national level influences the development of sustainable logistics, both in a synthetic perspective and through its three fundamental dimensions: economic, social, and environmental. The study is grounded in the assumption that enterprises increasingly play a crucial role in shaping sustainable development processes, not only through their direct business activities but also through their influence on supply chains, resource utilisation, innovation, and stakeholder relations. As a result, the diffusion of sustainable entrepreneurial practices may constitute an important driver of transformation within the logistics sector.

The central research question this study addresses is: Can the development of enterprises operating in accordance with the principles of sustainable entrepreneurship contribute to advancing sustainable logistics at the national level? In addition, the study seeks to determine whether this impact is immediate or delayed, and whether it affects the individual dimensions of sustainable logistics differently.

Previous literature has extensively examined the determinants of logistics development, the role of sustainability in supply chains, and the growing importance of sustainable entrepreneurship and ESG-oriented business models. Numerous studies have analysed the influence of innovation, institutional conditions, environmental regulations, and economic development on logistics performance and sustainability outcomes. At the same time, research on sustainable entrepreneurship has primarily focused on firm-level behaviour, organisational capabilities, innovation processes, and the creation of social and environmental value.

Despite the growing body of literature, relatively little attention has been devoted to analysing the direct relationship between sustainable entrepreneurship and sustainable logistics at the macroeconomic level. Existing studies typically examine these phenomena separately or focus on selected aspects of sustainability without investigating their mutual interactions. Moreover, empirical evidence concerning the dynamic nature of this relationship remains limited. In particular, there is a noticeable lack of studies employing synthetic sustainability indicators and econometric approaches capable of capturing both contemporaneous and lagged effects between sustainable entrepreneurship and logistics development.

This study attempts to address this research gap by developing synthetic measures of sustainable entrepreneurship and sustainable logistics and by examining their interrelationships in two European countries characterised by different development trajectories. The empirical analysis combines descriptive statistics, correlation analysis, Ordinary Least Squares (OLS) estimation, and Seemingly Unrelated Regression (SUR) models, enabling the identification of both direct and delayed effects of sustainable entrepreneurship on logistics sustainability.

The contribution of this study is threefold. First, it provides empirical evidence on the relationship between sustainable entrepreneurship and sustainable logistics at the national level. Second, it captures the multidimensional character of sustainable logistics by separately analysing its economic, social, and environmental pillars. Third, it identifies the temporal structure of these relationships, showing whether sustainability-oriented entrepreneurial activities generate immediate outcomes or require time before their effects become visible in the logistics sector. The findings may contribute to the development of sustainability research and offer practical implications for policymakers, business leaders, and stakeholders responsible for designing strategies to support sustainable economic transformation.

3.2. Purpose of the article and research hypotheses

This study aims to empirically verify the impact of the overall sustainability index of sustainable entrepreneurship on the level of the sustainable logistics index in Italy and Poland.

This analysis aims to determine whether sustainable entrepreneurship is a factor that determines the transformation of the logistics sector and to examine the nature of this impact on the individual pillars of sustainable logistics: economic, social, and environmental.

The specific objectives of the article include:

- examine the impact of sustainable entrepreneurship (SE) on the overall sustainable logistics index (SL),
- determining whether the strength and direction of this impact differ between the pillars of sustainable logistics,
- verifying whether the relationships among the analysed variables are systemic and interdependent and justifying the use of SUR models, which allow consideration of interconnections among the pillars.

Based on the literature review and the adopted in the research, the following research hypotheses were formulated:

- Main hypothesis:
  H0: Sustainable entrepreneurship has a statistically significant impact on the level of sustainable logistics.
- Specific hypotheses:
  H1: An increase in the level of sustainable entrepreneurship has a positive impact on the overall level of sustainable logistics.
  H2: Sustainable entrepreneurship influences the economic, social, and environmental pillars of sustainable logistics in different ways, with the direction and strength of these effects varying across countries and time periods.
  H3: There is structural interdependence between the pillars of sustainable logistics, which justifies the use of SUR models.

The objective and hypotheses, formulated in this way, allow a systematic examination of the impact of sustainable entrepreneurship on the logistics sector and drawing practical conclusions for economic policy and corporate strategies in the area of sustainable development.

3.3. Data and scope of the study

The study employs annual data for Italy and Poland from 2008 to 2023, a period marked by both economic stability and significant disruptions, including the aftermath of the global financial crisis, the COVID-19 pandemic, and the expansion of sustainability-focused EU regulations. This timeframe enables the observation of long-term trends and structural changes resulting from the growing focus on sustainability, providing a basis to assess sustainable entrepreneurship and logistics across varying economic and institutional conditions.

Country selection focused on contrasting economic and developmental profiles. Italy represents a mature European economy with an established logistics infrastructure, sustainability policies, and a relatively stable economic trajectory. In contrast, Poland is experiencing rapid economic growth and evolving sustainability approaches. Comparing these two countries thus reveals differences in how sustainable entrepreneurship contributes to

sustainable logistics development. Their shared EU regulatory context supports comparability while maintaining meaningful structural contrasts.

All data are annual and come from Eurostat. We chose Eurostat because it provides harmonised, consistent statistics for European countries, ensuring reliable comparison over time and between countries. Using a single source reduces the risks of measurement inconsistency and makes the analysis more reliable. Eurostat also covers many economic, social, environmental, and sectoral indicators, making it ideal for building synthetic measures of sustainable entrepreneurship and logistics.

3.4. Level of analysis, variable construction, and synthetic indicator procedure

The analysis was carried out at two complementary research levels, capturing both the broad macroeconomic context and the sectoral specificity of the phenomenon under study. The first level adopts a macroeconomic (national) approach and addresses the category of sustainable entrepreneurship, while the second level adopts a sectoral approach, focussing on Section H (transport and storage), which is relevant for the analysis of sustainable logistics. This allows the simultaneous examination of the relationship between the overall level of economic development and its sectoral implications, thereby making a significant contribution to causal analysis.

In the study, two synthetic indicators were used: the Sustainable Entrepreneurship Index (SE) and the Sustainable Logistics Index (SL). Both indicators are based on analogous partial variables assigned to the three pillars of sustainable development: environmental (ENVE or ENVL), economic (ECOE or ECOL), and social (SOCE or SOCL). However, they differ in their level of aggregation and analytical function. The SE is macroeconomic in nature and was constructed on a per capita basis. It enables comparability between countries with different economic scales. SL, on the other hand, directly addresses the transport and warehousing sector, reflecting its specific structural and operational conditions.

Despite the use of similar partial indicators, the analysed constructs are not identical; they serve different analytical functions. In particular, SE and SL are treated as explanatory variables, allowing identification of the impact of the overall level of sustainable entrepreneurship on the development of sustainable logistics in the sector studied. This distinction is of crucial methodological significance and strengthens the interpretative coherence of the research model.

The construction of synthetic indicators is based on three pillars, each with specific diagnostic variables assigned to it.

The environmental pillar includes, in tons: carbon dioxide, methane, nitrous oxide, sulphur oxides (SO_2 equivalent), carbon monoxide, nitrogen oxides, and ammonia.

The economic pillar includes: enterprises – number, turnover or gross premiums written – million euros, personnel costs in total purchases of goods and services – percentage, production value – million euros, value added at factor cost – million euros, gross operating surplus –

million euros, total purchases of goods and services – million euros, gross investment in tangible goods – million euros, share of personnel costs in production – percentage, average personnel costs (personnel costs per employee) – thousand euros, gross operating rate – percentage, and share of gross operating surplus in value added – percentage.

The social pillar includes: wages and salaries – one million euros, social security costs – one million euros, employees – number, turnover per person employed – one thousand euros, apparent labour productivity (gross value added per person employed) – one thousand euros, wage adjusted labour productivity (apparent labour productivity by average personnel costs) – percentage, gross value added per employee – one thousand euros, growth rate of employment – percentage, persons employed per enterprise – number, share of personnel costs in total purchases of goods and services – percentage, and investment per person employed – thousands of euros.

During the construction of synthetic indicators, variables were classified as stimulants or destimulants.

Destimulants included all environmental variables and selected economic and social variables of a cost nature, that is, share of personnel costs in production – percentage, average personnel costs (personnel costs per employee) - 1000 euros, share of personnel costs in total purchases of goods and services – percentage. The remaining variables were classified as stimulants.

In the next step, a variable normalisation procedure was applied.

The following formula was used for stimulants:

$$z_{ijt} = \frac{x_{ijt}}{\max(x_{jt})},$$

and for destimulants:

$$z_{ijt} = \frac{\min(x_{jt})}{x_{ijt}},$$

where:

x_{ijt} - value of the jth diagnostic variable for the ith country in period t,

z_{ijt} - normalised value of the jth diagnostic variable for the i-th country in period t,

max_{jt} - maximum value of the jth variable in the set of all countries and periods covered by the analysis,

min_{jt} - minimum value of the jth variable in the set of all countries and periods covered by the analysis,

i - country index (i = 1, 2; Italy, Poland),

j - index of the diagnostic variable,

t - time index (year).

This normalisation ensures the comparability of variables with different units of measurement and eliminates scale effects, while accounting for their direction of impact.

In the next step, partial-pillar indices were constructed as arithmetic means of the normalised variables.

$$ECO_{it} = \frac{1}{n_{ECO}} \sum z_{ijt}, SOC_{it} = \frac{1}{n_{SOC}} \sum z_{ijt}, ENV_{it} = \frac{1}{n_{ENV}} \sum z_{ijt},$$

where:

$n_{ECO}, n_{SOC}, n_{ENV}$ – the number of diagnostic variables assigned to the economic, social, and environmental pillars, respectively,

ECO_{it} – the value of the synthetic indicator of the economic pillar for the ith country in period t,

SOC_{it} – the value of the synthetic indicator of the social pillar for the ith country in period t,

ENV_{it} – the value of the synthetic indicator of the environmental pillar for the ith country in period t.

Finally, the synthetic indicators of sustainable entrepreneurship and sustainable logistics were determined as the average of the three pillars.

$$SE_{it} = \frac{ECOE_{it} + SOCE_{it} + ENVE_{it}}{3},$$

$$SL_{it} = \frac{ECOL_{it} + SOCL_{it} + ENVL_{it}}{3}.$$

The use of equal weights in constructing the synthetic indicators was adopted to ensure methodological transparency and comparability across countries, periods, and dimensions (OECD, 2008). This approach avoids subjective prioritisation of individual pillars and allows the economic, social, and environmental dimensions to contribute equally to the overall sustainability measure. However, it should be acknowledged that equal weighting may affect the sensitivity of the results, as different weighting schemes could produce slightly different values for the composite indicators. Therefore, the adopted indices should be interpreted as synthetic approximations of sustainable entrepreneurship and sustainable logistics, rather than as exhaustive measures of these phenomena.

Indicators were constructed to maintain methodological consistency between the levels analysed. The adopted procedure for constructing synthetic indicators aligns with the multidimensional comparative analysis approach and enables a comprehensive assessment of complex phenomena such as sustainable entrepreneurship and sustainable logistics.

3.5. Research Methods, Econometric Modelling, and Model Validation

Empirical analysis used a set of complementary research methods that allowed the description and identification of relationships between the variables studied. The first stage involved trend analysis and basic descriptive statistics (maximum and minimum values, mean, standard deviation, and median), which allowed a preliminary characterisation of variable distributions, identification of their dynamics over time, and detection of potential outliers. The correlation analysis was then performed using Pearson, Spearman, Kendall, and Gamma coefficients, enabling the identification of linear, nonlinear, and monotonic relationships among

the indicators. Interpretation of the strength of the relationship was based on standard ranges of correlation coefficient values, where values close to 0 indicate no relationship, the range 0.0-0.3 indicates a weak relationship, 0.3-0.5 moderate, 0.5-0.7 good, 0.7-0.9 strong, and values above 0.9 indicate a very strong relationship. Similar ranges were adopted for negative values.

In the remainder of the study, linear regression models estimated by ordinary least squares (OLS) were used, serving as the primary tool to identify the impact of sustainable entrepreneurship on sustainable logistics. The coefficient of determination R^2 was used as a measure of model fit, with values interpreted as follows: below 0.3 – poor model fit, 0.3-0.6 – moderate fit, 0.6-0.8 – good fit, and above 0.8 – very good fit. Furthermore, the adjusted coefficient of determination was analysed, which allowed the inclusion of the number of explanatory variables and reduced the risk of overestimating the model quality.

In the first stage of modelling, a classic OLS linear regression model was used, in the following form:

$$SL_{it} = \alpha + \beta_1 SE_{it} + \beta_2 SE_{it-1} + \beta_3 SE_{it-2} + \beta_4 SE_{it-3} + \beta_5 SE_{it-4} + \varepsilon_{it},$$

where:

SL_{it} - the Sustainable Logistics Index in country i and year t,

SE_{it} - the Sustainable Entrepreneurship Index in country i and year t,

ε_{it} - the error term.

This model was extended to include lagged values of the SE variable, enabling analysis of short- and medium-term effects and enhancing the model's ability to represent real-world economic processes. The introduction of lagged values for the SE variable stems from the dynamic nature of the analysed processes. The impact of sustainable entrepreneurship on the logistics sector is not immediate; It unfolds over time due to investment processes, organisational changes, and the gradual diffusion of sustainable development practices. The choice of lag lengths was empirical – various lag structures were tested, and only those that proved statistically significant were included in the final model specification.

To ensure the validity of the inferences, a wide range of verification procedures were conducted that covered key assumptions of the classical linear regression model. The following were verified:

- linearity in parameters,
- no perfect multicollinearity,
- zero expected value of the random term,
- homoscedasticity (White's test),
- no first-order autocorrelation (Durbin-Watson test),
- There is no higher-order autocorrelation, including second-order autocorrelation.

Furthermore, tests were conducted for the normality of the residual distribution, which is particularly important for the accuracy of statistical inference in small samples.

In the second stage of modelling, the SUR model was used, in which the dependent variable is the individual pillars of sustainable logistics.

$$ECOL_{it} = \alpha + \beta_1 SE_{it} + \beta_2 SE_{it-1} + \beta_3 SE_{it-2} + \beta_4 SE_{it-3} + \beta_5 SE_{it-4} + SCOL_{it} + ENVL_{it} + \varepsilon_{it}$$

$$SOCL_{it} = \alpha + \beta_1 SE_{it} + \beta_2 SE_{it-1} + \beta_3 SE_{it-2} + \beta_4 SE_{it-3} + \beta_5 SE_{it-4} + ECOL_{it} + ENVL_{it} + \varepsilon_{it}$$

$$ENVL_{it} = \alpha + \beta_1 SE_{it} + \beta_2 SE_{it-1} + \beta_3 SE_{it-2} + \beta_4 SE_{it-3} + \beta_5 SE_{it-4} + ECOL_{it} + SOCL_{it} + \varepsilon_{it}$$

This method allows for interdependencies between model components by correlating random terms across equations (this leads to more efficient estimators than estimating separate equations using OLS). Furthermore, this approach allows for a more in-depth analysis of differences in the impact of the SE variable on the individual pillars of sustainable logistics.

The main limitations of this study include a small sample size (T = 16) due to the limited availability of comparable statistical data and the inclusion of only two economies in the analysis.

Although the empirical procedure includes a broad set of model validation tests, the results should nevertheless be interpreted with methodological caution. The use of synthetic indicators, while useful for capturing multidimensional phenomena, may be sensitive to the selection of diagnostic variables, the normalisation procedure, and the equal-weighting scheme adopted in the study. In addition, the relationships analysed may be influenced by omitted variables such as infrastructure quality, public investment, regulatory changes, energy prices, digitalisation processes, and sector-specific technological development.

Another important limitation concerns the potential endogeneity of the relationship between sustainable entrepreneurship and sustainable logistics, as more developed logistics systems may simultaneously facilitate the diffusion of sustainable entrepreneurial practices. Therefore, the results should primarily be interpreted as evidence of statistically observed relationships rather than definitive causal effects. Instead, the findings support evolutionary and path-dependence approaches, which suggest that sustainability-oriented transformation processes are cumulative, institutionally conditioned, and characterised by delayed adjustment mechanisms. The study also confirms the importance of analysing sustainable development dimensions simultaneously, as significant interdependencies and trade-offs may arise between economic, social and environmental objectives. Future studies could strengthen the robustness of the analysis by extending the sample to a larger group of countries, applying alternative weighting procedures, introducing additional control variables, and using more advanced dynamic panel methods.

However, it allows for the development of conclusions that will serve as a basis for researching this issue in other countries. In the longer term, the analysis is planned to be expanded to a broader set of economies. It, combined with the adopted methodology, which allows for the identification of the directions and nature of relationships between variables and the capture of their dynamics over time, will enable the verification of relationships across more diverse contexts and the formulation of conclusions with greater validity.

4. Research Results

Graph 1 presents the values of the Sustainable Logistics Index and its components from 2008 to 2023, along with trend lines, for the analysed countries, Italy and Poland. The data presented demonstrate the variability and direction of change in the three components of Sustainable Logistics (SL). Economic (ECOL), Social (SOCL), and Environmental (ENVL), as well as their synthetic representation in SL.

ECOL indicates various development paths. In Italy, this indicator remained relatively stable for a long time (a significant increase occurred only after 2020). The positive coefficient for the time variable indicates an upward trend, while the moderate R^2 suggests some time variability. In Poland, on the other hand, a clear and systematic upward trend is observed, as confirmed by the positive and relatively high coefficient for the time variable, and the high R^2 (0.9239) indicates a very good fit of the model to the data.

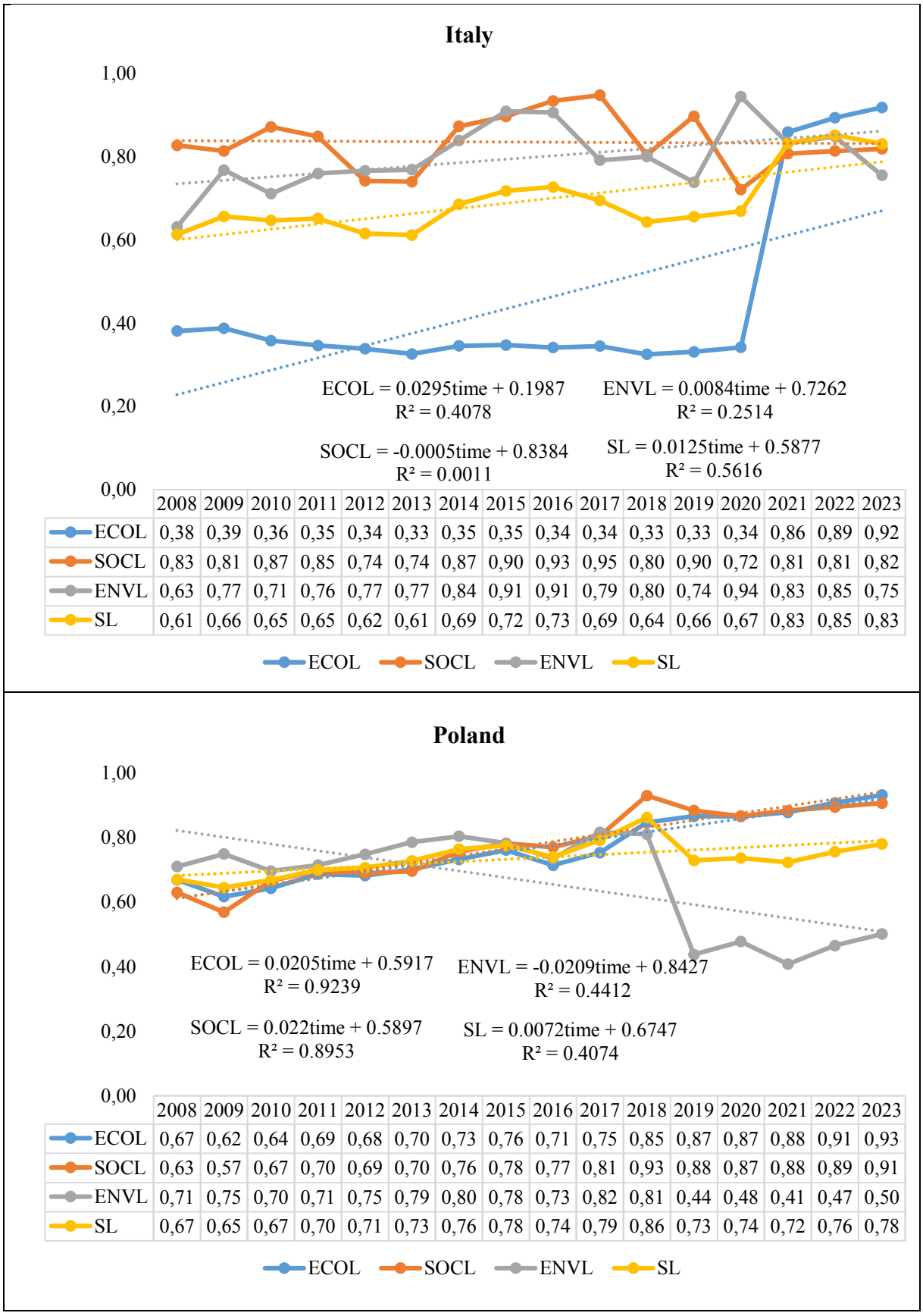
Taking into account the SOCL values, the level of development in the countries varies, and the dynamics of change differs. In the case of Italy, the trend equation indicates a practically zero, slightly decreasing trend. The very low coefficient of determination ($R^2 = 0.0011$) confirms the poor fit of the linear model. On the other hand, the positive slope and high R^2 (0.8953) indicate systematic improvement and a good fit of the model to the data.

The greatest differences between the countries analysed are visible in ENVL. In Italy, a positive coefficient for the time variable indicates a gradual improvement in pro-environmental activities, although a moderate R^2 suggests some fluctuations. In Poland, however, the slope is negative, indicating a downward trend, and the relatively low R^2 (0.4412) indicates a limited model fit and greater data variability.

SL in both countries shows an upward trend, but the nature of the trend differs. In Italy, a positive coefficient for the time variable and a moderate R^2 indicate relatively stable growth. In Poland, a positive trend is also observed, but its slope is smaller, and the lower R^2 (0.4074) reflects greater fluctuations in the indicator over time.

In summary, both countries are seeing improvements in sustainable logistics, although the underlying conditions differ. In Italy, development is more even and stable, while in Poland, strong economic and social growth is partially constrained by negative environmental trends.

The negative trends observed for the environmental pillar may indicate the presence of green transition trade-offs, particularly in economies undergoing intensive structural transformation. In the short and medium term, expansion of the logistics sector may increase transport intensity, energy consumption, and emissions more rapidly than environmental innovations can offset. This may also reflect delayed technological adoption and insufficient environmental infrastructure (Sonar et al., 2024; Ferraro et al., 2026).



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
ECOL	0,38	0,39	0,36	0,35	0,34	0,33	0,35	0,35	0,34	0,34	0,33	0,33	0,34	0,86	0,89	0,92
SOCL	0,83	0,81	0,87	0,85	0,74	0,74	0,87	0,90	0,93	0,95	0,80	0,90	0,72	0,81	0,81	0,82
ENVL	0,63	0,77	0,71	0,76	0,77	0,77	0,84	0,91	0,91	0,79	0,80	0,74	0,94	0,83	0,85	0,75
SL	0,61	0,66	0,65	0,65	0,62	0,61	0,69	0,72	0,73	0,69	0,64	0,66	0,67	0,83	0,85	0,83

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
ECOL	0,67	0,62	0,64	0,69	0,68	0,70	0,73	0,76	0,71	0,75	0,85	0,87	0,87	0,88	0,91	0,93
SOCL	0,63	0,57	0,67	0,70	0,69	0,70	0,76	0,78	0,77	0,81	0,93	0,88	0,87	0,88	0,89	0,91
ENVL	0,71	0,75	0,70	0,71	0,75	0,79	0,80	0,78	0,73	0,82	0,81	0,44	0,48	0,41	0,47	0,50
SL	0,67	0,65	0,67	0,70	0,71	0,73	0,76	0,78	0,74	0,79	0,86	0,73	0,74	0,72	0,76	0,78

Figure 1. Sustainable Logistics Index in Italy and Poland, 2008-2023.

Source: Authors' elaboration based on Eurostat data.

Graph 2 presents the values of the Sustainable Entrepreneurship Index and its components from 2008 to 2023 for the countries – Italy and Poland – along with trend lines. The data presented demonstrate the variability and direction of change in the three key dimensions of sustainable entrepreneurship (SE): economic (ECOE), social (SOCE), and environmental (ENVE), as well as their synthetic representation in the SE.

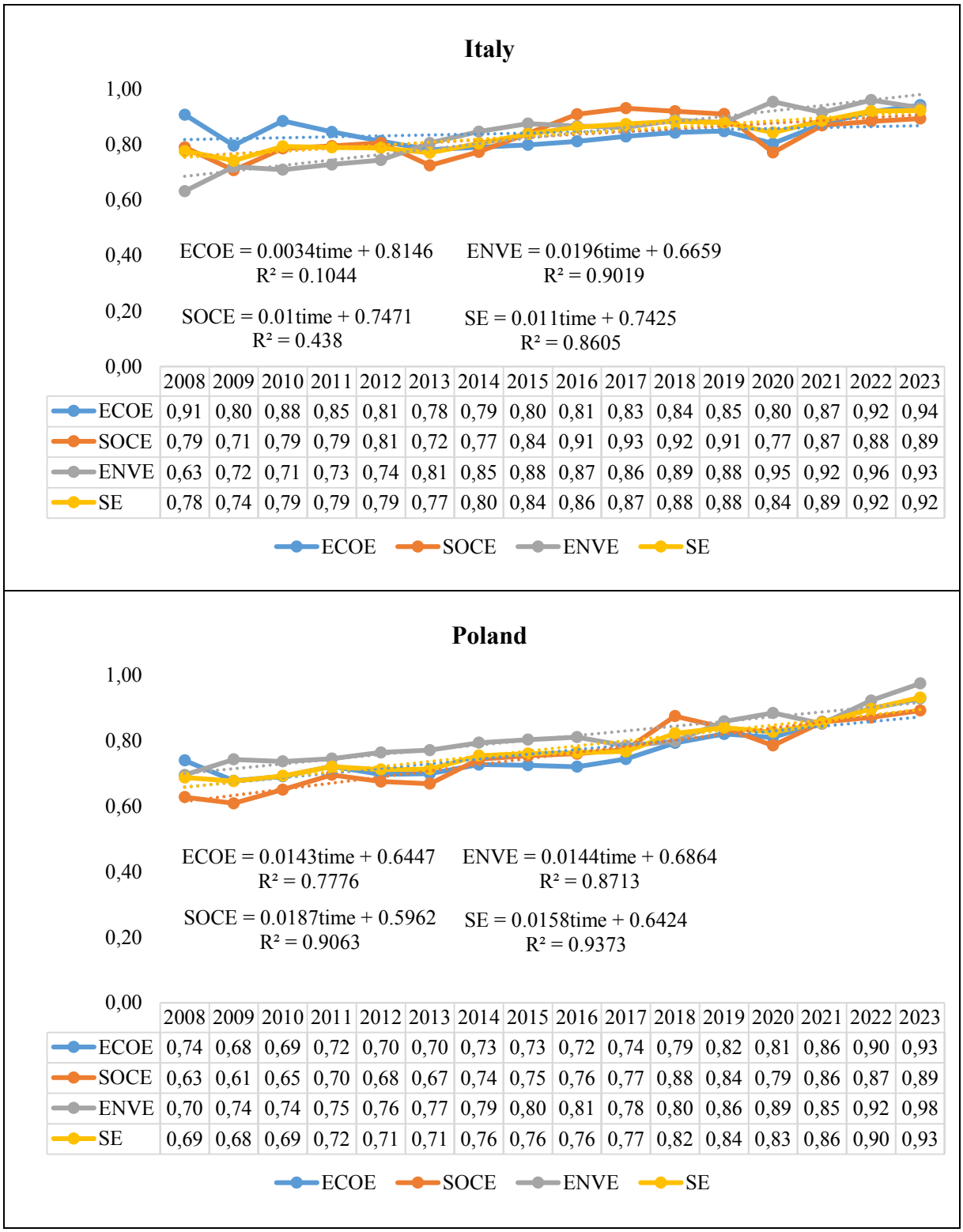
ECOE indicates different development pathways between the countries analysed. In Italy, this indicator shows a relatively stable course with minor fluctuations and a weak upward trend, as confirmed by the low coefficient value for the time variable and the very low R^2 (0.1044), indicating a poor fit of the linear model. However, in Poland, a clear upward trend is observed: index values increase from 0.74 in 2008 to 0.93 in 2023, and positive slope and high R^2 (0.7776) indicate systematic improvement and good model fit.

With respect to SOCE, improvements are visible in both countries, though with varying intensity. In Italy, a moderate upward trend is observed and an average model fit ($R^2 = 0.438$), indicating a gradual but less stable improvement. In Poland, on the other hand, this component shows a strong and stable upward trend – values increase from 0.63 to 0.89 - and the high R^2 (0.9063) confirms a very good model fit and consistent development over time.

ENVE in both countries shows a clear upward trend (although the pace and final level differ). In Italy, the slope (0.0196) and the high R^2 (0.9019) indicate rapid and systematic improvement in environmental entrepreneurship. In Poland, the trend is also positive, with a slightly lower growth rate (0.0144) and high model fit ($R^2 = 0.8713$), while the index values reach a higher final level in 2023 (0.98), which may indicate an intensification of pro-environmental activities in recent years.

SE in both countries shows a clear upward trend. In Italy, growth is stable, with a moderately high model fit ($R^2 = 0.8605$), indicating a systematic improvement in the level of sustainable entrepreneurship, starting from a higher initial level (0.7425). In Poland, the growth rate is even more pronounced (slope = 0.0158), and the very high $R^2 = 0.9373$ indicates an excellent fit of the model and consistent growth across all dimensions analysed, despite the lower initial level (0.6424).

In summary, both countries are seeing significant improvements in sustainable entrepreneurship. In Italy, growth is mainly driven by the environmental component, with the economic component relatively stable. Poland, on the other hand, is characterised by more even and dynamic growth in all areas analysed, resulting in a stronger and more consistent increase in the SE.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
ECOE	0,91	0,80	0,88	0,85	0,81	0,78	0,79	0,80	0,81	0,83	0,84	0,85	0,80	0,87	0,92	0,94
SOCE	0,79	0,71	0,79	0,79	0,81	0,72	0,77	0,84	0,91	0,93	0,92	0,91	0,77	0,87	0,88	0,89
ENVE	0,63	0,72	0,71	0,73	0,74	0,81	0,85	0,88	0,87	0,86	0,89	0,88	0,95	0,92	0,96	0,93
SE	0,78	0,74	0,79	0,79	0,79	0,77	0,80	0,84	0,86	0,87	0,88	0,88	0,84	0,89	0,92	0,92

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
ECOE	0,74	0,68	0,69	0,72	0,70	0,70	0,73	0,73	0,72	0,74	0,79	0,82	0,81	0,86	0,90	0,93
SOCE	0,63	0,61	0,65	0,70	0,68	0,67	0,74	0,75	0,76	0,77	0,88	0,84	0,79	0,86	0,87	0,89
ENVE	0,70	0,74	0,74	0,75	0,76	0,77	0,79	0,80	0,81	0,78	0,80	0,86	0,89	0,85	0,92	0,98
SE	0,69	0,68	0,69	0,72	0,71	0,71	0,76	0,76	0,76	0,77	0,82	0,84	0,83	0,86	0,90	0,93

Figure 2. Sustainable Entrepreneurship Index in Italy and Poland, 2008-2023

Source: Authors' elaboration based on Eurostat data.

Table 1 presents basic descriptive statistics for SL and SE in Italy and Poland from 2008 to 2023. The presented measures allow for assessing the levels, variations, and distributions of the analysed indicators in both countries.

For SL, higher mean values were recorded in Poland (0.74) than in Italy (0.69), indicating a generally higher level of this indicator during the period studied. Poland also has a higher minimum value (0.65) than 0.61. The maximum values are similar (0.86 in Poland and 0.85 in Italy). The lower standard deviation in Poland (0.05) compared to Italy (0.08) indicates a lower variability of the data, confirming greater stability. The median is also higher in Poland (0.73) than in Italy (0.66), reinforcing the conclusion that sustainable logistics is higher and more evenly distributed in Poland.

The situation is different for SE. A higher mean value was recorded in Italy (0.84) than in Poland (0.78), indicating a higher overall level of this indicator in that country. The maximum values are similar (0.93 in Poland and 0.92 in Italy). Italy has a lower minimum value (0.74 vs. 0.68), suggesting a more stable level of the indicator over time. The standard deviation is lower in Italy (0.05) than in Poland (0.08), indicating less variability and greater predictability of SE values. The median for Italy (0.84) is also higher than that for Poland (0.76), confirming the indicator's higher central tendency.

In summary, Poland achieves better results in sustainable logistics, characterised by higher mean values and lower variability. Italy, on the other hand, stands out for its higher level of sustainable entrepreneurship and, at the same time, has a more stable indicator over the analysed period. These results indicate different development profiles of the two countries in the areas of sustainable development.

Table 1.
Sustainable Logistics Index and Sustainable Entrepreneurship Index in Italy and Poland, 2008-2023 - Basic descriptive statistics

Indicator		**SL**		**SE**	
Counrty		**Italy**	**Poland**	**Italy**	**Poland**
Basic descriptive statistics	Max	0.85	0.86	0.92	0.93
	Min	0.61	0.65	0.74	0.68
	Mean	0.69	0.74	0.84	0.78
	SD	0.08	0.05	0.05	0.08
	Median	0.66	0.73	0.84	0.76

Source: Authors' elaboration based on Eurostat data.

Table 2 shows the results of the correlation analysis between SL and SE in Italy and Poland from 2008 to 2023. The use of several correlation measures (Pearson, Spearman, Gamma, and Kendall) provides a more comprehensive assessment in terms of the strength and nature of the relationships between the variables analysed.

In Italy, all the coefficients indicate a relatively strong positive relationship between SL and SE. The Pearson linear correlation coefficient is 0.76, indicating a strong positive relationship: an increase in the level of sustainable logistics is accompanied by an increase in the level of sustainable entrepreneurship. Similar conclusions follow from nonparametric measures: Spearman's coefficient (0.71) also indicates a strong monotonic relationship, while the values of the Gamma (0.55) and Kendall (0.55) coefficients suggest moderate but clear rank

agreement. Indicates that the indicators relationship between the analysed in Italy is stable and relatively strong, regardless of the measurement method adopted.

In Poland, a positive correlation between SL and SE is also observed, but its strength is significantly lower than in Italy. The Pearson coefficient is 0.59, indicating a moderate linear correlation. The Spearman coefficient (0.66) suggests a moderately strong monotonic relationship, while the Gamma coefficient (0.50) and Kendall coefficient (0.50) indicate moderate rank agreement. These results indicate that, while an increase in sustainable entrepreneurial activity accompanies the growth of sustainable logistics in Poland, this relationship is less pronounced and more diverse than in Italy.

In summary, a positive correlation between sustainable logistics and sustainable entrepreneurship is observed in both countries (it is stronger in Italy than in Poland). In Italy, the development of these two areas is more interconnected and complementary, whereas in Poland, this relationship is weaker and may be influenced by additional external factors.

Table 2.
Sustainable Logistics Index and Sustainable Entrepreneurship Index in Italy and Poland, 2008-2023 - Correlation

Correlation, 2008-2023		
Correlation coefficient	**Italy**	**Poland**
	SL/SE	**SL/SE**
Pearson's R	0.76	0.59
Spearman's Rho	0.71	0.66
Gamma	0.55	0.50
Kendall rank	0.55	0.50

Source: Authors' elaboration based on Eurostat data.

Table 3 presents the OLS estimation results for Italy and Poland, where SL is the dependent variable and current and lagged SE values are the explanatory variables.

In the case of Italy, the resulting model shows a very high degree of fit ($R^2 = 0.823$), indicating that more than 82% of the variability in the dependent variable is explained by the adopted set of regressors. Parameter analysis indicates that the current SE value has a positive and statistically significant effect on SL ($p = 0.0090$). A one-period delay in SE has the opposite effect ($p = 0.0205$). The SE variable, lagged by 4 periods, again shows a positive effect ($p = 0.0459$). The results obtained suggest a dynamic and time-varying mechanism of the impact of SE on SL. The effect is positive in the short term and then reverses, only to become positive again in the long term. The occurrence of negative lagged coefficients may reflect short-term adjustment costs associated with sustainability-oriented transformation processes. Implementing sustainable business practices often requires organizational restructuring, technological adaptation, compliance with environmental regulations, and substantial investment, which may temporarily reduce operational efficiency in the logistics sector before long-term benefits become apparent (Palkina, 2022; Jayarathna et al., 2024). Therefore, the coexistence of negative short-term and positive long-term effects supports the assumption

that the relationship between sustainable entrepreneurship and sustainable logistics is dynamic, cumulative and non-linear.

In the case of Poland, the model has a significantly lower fit ($R^2 = 0.389$), indicating that the included variables explain only a portion of the variability of SL. Unlike in Italy, the current SE value is not statistically significant, whereas its lags are. In particular, a one-period delay shows a negative effect that approaches statistical significance ($p = 0.0512$), while a four-period delay shows a positive and significant effect ($p = 0.040$). The constant is statistically significant, suggesting the presence of other unaccounted for factors influencing SL. The results suggest that in Poland the relationship between the analysed variables is more time-distributed, with effects manifesting primarily with lag.

Verification of the assumptions of the classical least-squares method confirms the validity of both models. In none of the cases were we able to detect heteroscedasticity (White's test), autocorrelation of the random component (LM tests and the Durbin-Watson statistic), or deviations from the normality of the residual distribution. Furthermore, the models are correctly specified, and multicollinearity is absent.

A comparison of the results for both countries reveals significant differences, including differences in the relationships between the variables. Italy is characterised by a stronger and more immediate response of the SL to changes in the SE, while in Poland, this relationship is weaker and more lagged. It may reflect structural differences between the economies and different transmission mechanisms of the analysed phenomena.

Table 3.
The OLS estimation, dependent variable: SL, explanatory variables: SE, SE(t-1), SE(t-2), SE(t-3), SE(t-4)

Italy				
Model 1: OLS, using observations 2008-2023 (T = 16)				
Dependent variable: SL				
Variable	**Coefficient**	**Std. error**	**P-value**	**R-squared**
const	−0.378	0.237	0.1488	0.823
SE	1.976	0.576	0.0090	
SE(t-1)	−1.620	0.562	0.0205	
SE(t-4)	0.939	0.398	0.0459	
Assumptions of OLS				
Assumption	**Test / Indicator**	**Result / Statistic**	**p-value**	**Assessment of fulfillment**
1. Linearity in parameters	Model specification	Linear model (const + SE + SE(t-1) + SE(t-4))	-	Fulfilled
2. There is no perfect multicollinearity	Estimation possible	All std. error finite, model stable	-	Fulfilled
3. Expected value of error = 0	Constant term in the model	Constant present	-	Fulfilled
4. Homoscedasticity	White's test	LM = 11.798; df = 9	0.225	Fulfilled
5. No autocorrelation of residuals (1st order)	LM test; DW	LMF = 0.479; DW = 1.445	0.511	Fulfilled
6. No autocorrelation of residuals (2nd order)	LM test	LMF = 0.339	0.726	Fulfilled
7. Normality of residuals	Test Chi²	$\chi^2(2) = 0.774$	0.679	Fulfilled

Poland				
Model 1: OLS, using observations 2008-2023 (T = 16)				
Dependent variable: SL				
Variable	**Coefficient**	**Std. error**	**P-value**	**R-squared**
Const	0.563	0.160	0.0064	0.389
SE(t-1)	−1.406	0.625	0.0512	
SE(t-4)	1.750	0.733	0.040	
Assumptions of OLS				
Assumption	**Test / Indicator**	**Result / Statistic**	**p-value**	**Assessment of fulfillment**
1. Linearity in parameters	Model specification	Linear model (const + SE_1 + SE_4)	–	Fulfilled
2. There is no perfect multicollinearity	Estimation possible	All std. error finite, model stable	–	Fulfilled
3. Expected value of error = 0	Constant term in the model	Constant present	–	Fulfilled
4. Homoscedasticity	White's test	LM = 5.996; df = 5	0.307	Fulfilled
5. No autocorrelation (1st order)	LM test; DW	LMF = 0.799; DW = 1.209	0.397	Fulfilled
6. No autocorrelation (2nd order)	LM test	LMF = 0.384	0.695	Fulfilled
7. Normality of residuals	Test Chi²	$\chi^2(2) = 0.684$	0.710	Fulfilled

Source: Authors' elaboration based on Eurostat data.

Table 4 presents the estimation results for the SUR models for Italy and Poland, which simultaneously estimate three equations with different dependent variables: ECOL, SOCL, and ENVL. The models include both current and lagged values of the SE variable, as well as interrelationships among the analysed areas (depending on the equation). Using the SUR method allows for potential correlation between random terms across equations, thereby increasing estimation efficiency.

To verify the validity of the SUR model, a Breusch–Pagan test was performed on the random term covariance matrix (which assesses whether the random terms across the individual equations are correlated, a key assumption that justifies the use of systemic estimation rather than separate OLS models).

In the case of Italy, no statistically significant correlation was found between the random terms was found ($p > 0.05$), indicating that there was no basis for rejecting the hypothesis of their independence. It may suggest weaker structural connections between the analysed pillars in this economy.

In the case of Poland, the results ($p < 0.01$) indicate a statistically significant correlation between the random terms in the equations, which confirms the existence of interdependencies between the pillars of sustainable logistics and the validity of the SUR model.

The results obtained indicate the varied nature of the interdependencies between the pillars of sustainable logistics in the countries studied.

In Italy, the results indicate varying levels of fit across the individual equations. The best fit was obtained for the SOCL equation ($R^2 = 0.677$), moderate for ECOL ($R^2 = 0.448$), and the poorest for ENVL ($R^2 = 0.181$). In the equation for ECOL, the positive effect of the current SE value is statistically significant ($p = 0.0110$), indicating that an increase

in SE directly increases the level of ECOL. In the SOCL equation, a strong positive effect of current SE ($p = 0.0010$) is also observed, while its one-period delay has a negative effect ($p = 0.0060$). Furthermore, the ECOL variable negatively affects SOCL ($p = 0.0046$), suggesting some substitutability between these two areas. The negative relationship between the economic and social pillars in Italy may indicate the presence of sustainability trade-offs within mature logistics systems. Improvements in economic efficiency may partly result from automation, process optimisation, labour rationalisation, and cost-reduction strategies, which can temporarily weaken certain social dimensions, such as employment dynamics or labour indicators.

In the ENVL equation, only the SE values are significant: a delay has a negative effect ($p = 0.0422$), while a delay has a positive effect ($p = 0.0367$), which confirms the presence of lagged effects.

In the case of Poland, the models show a very high fit for the ECOL equations ($R^2 = 0.976$) and SOCL ($R^2 = 0.922$) and a relatively high fit for ENVL ($R^2 = 0.724$). In the ECOL equation, the SE variable lagged by four periods plays a key role ($p = 0.0057$), and the relationships with the other variables are also significant. SOCL has a positive effect ($p < 0.001$), while ENVL has a negative effect ($p = 0.0124$). In the SOCL equation, the SE(t-4) lagged effect is also significant, but its effect is negative ($p = 0.0289$). At the same time, ECOL has a strong positive effect ($p < 0.001$), and ENVL has a positive effect ($p = 0.0159$), indicating the complementarity of these areas. In the ENVL equation, the only significant explanatory variable is SE lagged by 1 period, with a significantly negative impact ($p = 0.0002$).

Comparison of the results of the SUR model for both countries reveals significant differences in the structure of relationships between the areas analysed. In Italy, the current value of the SE variable dominates, and the interrelationships among ECOL, SOCL, and ENVL are relatively weak and time-limited. However, in Poland, lagged SE effects play a key role, as do clear and positive relationships between the dimensions studied, indicating their significant integration and complementary nature.

Table 4.
The SUR estimation, dependent variables: ECOL, SOCL, ENVL, explanatory variables: SE, SE(t-1), SE(t-2), SE(t-3), SE(t-4) and ECOL, SOCL, ENVL (depending on the model)

Italy				
Model 2: SUR, using observations 2008-2023 (T = 16)				
Equation 1				
Dependent variable: ECOL				
	Coefficient	Std. error	P-value	R-squared
const	−2.338	0.905	0.0272	0.448
SE	3.287	1.055	0.0110	

Cont. table 4.

Equation 2				
Dependent variable:SOCL				
	Coefficient	Std. error	P-value	R-squared
const	0.021	0.270	0.9389	0.677
SE	3.140	0.627	0.0010	
SE(t-1)	−2.071	0.559	0.0060	
ECOL	−0.266	0.068	0.0046	
Equation 3				
Dependent variable: ENVL				
	Coefficient	Std. error	P-value	R-squared
const	0.933	0.327	0.0190	0.181
SE(t-2)	−1.358	0.574	0.0422	
SE(t-4)	1.255	0.512	0.0367	
Cross-equation VCV for residuals				
	0.0316	(0.033)	(−0.501)	
	0.0002	0.0017	(−0.232)	
	−0.0053	−0.0006	0.0035	
Tests				
Breusch-Pagan test for diagonal covariance matrix				
Chi-square(3) = 3.67133 [0.2992]				
log determinant = -15.8171				
Poland				
Model 2: SUR, using observations 2008-2023 (T = 16)				
Equation 1				
Dependent variable: ECOL				
	Coefficient	Std. error	P-value	R-squared
const	−0.011	0.102	0.9174	0.976
SE(t-4)	0.558	0.149	0.0057	
SOCL	0.571845	0.069	3.22e-05	
ENVL	−0.109	0.034	0.0124	
Equation 2				
Dependent variable:SOCL				
	Coefficient	Std. error	P-value	R-squared
const	0.005	0.176	0.9759	0.922
SE(t-4)	−0.902	0.339	0.0289	
ECOL	1.699	0.204	3.22e-05	
ENVL	0.187	0.062	0.0159	
Equation 3				
Dependent variable: ENVL				
	Coefficient	Std. error	P-value	R-squared
const	2.529	0.336	2.00e-05	0.724
SE(t-1)	−2.392	0.426	0.0002	
Cross-equation VCV for residuals				
	0.0002	(−0.999)	(−0.088)	
	−0.0003	0.0005	(0.077)	
	−9.7808e-05	0.0001	0.0074	
Tests				
Breusch-Pagan test for diagonal covariance matrix				
Chi-square(3) = 12.1334 [0.0069]				
log determinant = -27.2246				

Source: Authors' elaboration based on Eurostat data.

In both countries studied, sustainable logistics and entrepreneurship are developing, but their nature differs. In Italy, the interdependencies between these areas are stronger and more stable, whereas in Poland they are more dynamic, less predictable, and often delayed.

5. Discussion of the Results

Empirical results confirm the existence of significant relationships between the level of sustainable entrepreneurship (SE) and the development of sustainable logistics (SL), but their nature and strength vary significantly between the countries analysed.

In the case of Italy, we observe stronger and more direct links between the studied phenomena. The high correlation coefficients and the very good fit of the regression models indicate that the development of sustainable entrepreneurship is translated relatively quickly into changes in the logistics sector. At the same time, the results of the OLS and SUR models reveal the nonlinear and dynamic nature of these relationships: the impact of SE changes over time, assuming both positive and negative values at various lag periods.

The presence of negative coefficients in some model specifications should not be interpreted as evidence that sustainable entrepreneurship directly reduces sustainable logistics development. Instead, these coefficients may indicate short-term adjustment costs, transition frictions, and delayed absorption of sustainability-oriented investments (Palkina, 2022; Jayarathna et al., 2024). Implementing sustainable business practices often requires restructuring logistics processes, investing in new technologies, adapting to regulatory requirements, and making organisational changes. These actions may temporarily weaken certain aspects of logistics performance before positive effects emerge in the longer term. Thus, the coexistence of negative short-term and positive long-term effects confirms the dynamic and non-linear nature of the relationship between sustainable entrepreneurship and sustainable logistics.

In Poland, negative lagged effects may also reflect the transitional nature of the economy, greater dependence on external financing mechanisms, and slower diffusion of sustainable technologies within the logistics sector (Rakyta et al., 2022; Sonar et al., 2024).

In Poland, these relationships are more dispersed and lagged. The lower values of the determination coefficients and the lack of significance of the current SE values in the models indicate that the impact of sustainable entrepreneurship on logistics is revealed primarily with delay. This may be due to the economic transformation phase and the greater role of external factors, such as public policy, EU funds, or structural changes in the transport sector.

Another important element of the difference in analysis is the dependencies in the structure between the pillars of sustainable logistics. In Poland, strong interdependencies between the pillars were confirmed (Breusch-Pagan test results), indicating their complementary nature. This means that changes in one area (e.g., economic) influence others (social and environmental). On the contrary, in Italy, the lack of significant correlations between the equations suggests greater autonomy between the individual pillars.

Different directions of change in the environmental pillar are also notable, particularly in Poland, where a downward trend is observed in environmental logistics despite the growth of sustainable entrepreneurship (Bartosiewicz et al., 2025). This may indicate insufficient effectiveness in implementing environmental solutions in the transport sector or the dominance of cost factors over environmental ones.

6. Conclusions and Practical Implications

The results of the study clearly confirm that sustainable entrepreneurship is a significant factor in the development of sustainable logistics, although the nature of this impact varies depending on the economic and structural conditions of the countries analysed. In particular, these relationships are dynamic and often manifest with delay, which means that the effects of implementing sustainable development practices are not immediate, but rather extended over time.

In Italy, a more direct and stable mechanism of sustainable entrepreneurship's impact on the logistics sector is observed, likely due to a higher level of institutional maturity and greater systemic cohesion. In Poland, however, these relationships are more complex and diffuse and their effects are revealed primarily in the longer term, indicating the significant role of intermediary factors such as public policy, infrastructure investments, and the absorption of EU funds. At the same time, the results indicate significant differences in the functioning of the individual pillars of sustainable logistics – the relative weakness of the environmental pillar is particularly noticeable, especially in Poland, where it has not seen consistent improvement despite the overall increase in sustainable entrepreneurship.

The identified relationships have significant practical implications. First, they point to the need for long-term and consistent policies supporting the development of sustainable entrepreneurship, as only within this time frame can lasting effects be achieved in the logistics sector (Ma et al. 2025). This means that economic policy instruments should be designed taking into account delays in the transmission of these effects and the need for stable support for structural transformation. Of particular importance here is the development of tools supporting the green transformation of logistics, including investments in low-emission technologies, the development of transport infrastructure, and regulations limiting the sector's negative environmental impact (Kucharski et al., 2025; Ferraro et al., 2026).

From the perspective of businesses, the results of the study emphasise the importance of considering sustainable development activities as part of a long-term strategy, not just a short-term response to regulatory or social pressure. Integrating economic, social, and environmental dimensions can generate synergistic effects, especially under conditions of strong systemic interconnections between these areas. At the same time, it is necessary to consider that the

implementation of sustainable solutions may involve temporary costs and a decrease in efficiency in the short term, which, however, leads to improved results in the long term.

The findings of the study also indicate the need to increase the effectiveness of environmental initiatives in the logistics sector, particularly in developing economies, where a lack of coherence is observed between the growth of sustainable entrepreneurship and the improvement of environmental indicators. From a practical perspective, the findings suggest that sustainable entrepreneurship can serve as an important catalyst for the transition towards more sustainable logistics systems. The results indicate that investments in ESG practices, green innovation, and sustainability-oriented business models may generate benefits not only at the firm level but also across logistics networks and supply chains. At the same time, the identified time-lagged effects imply that the benefits of sustainability initiatives may not be visible immediately and therefore require a long-term strategic perspective from both managers and policymakers. The differences observed between Italy and Poland further suggest that sustainability policies and support mechanisms should be adapted to national institutional and economic conditions rather than implemented through a uniform approach. These findings may support decision-makers in designing more effective strategies for sustainable economic and logistics development.

In summary, the conducted indicate that an effective transformation of the logistics sector toward sustainable development requires coordinated actions at the macroeconomic and microeconomic levels, taking into account both national specificities and the long-term nature of the processes being analysed. From a theoretical perspective, the study contributes to the literature by demonstrating that the relationship between sustainable entrepreneurship and sustainable logistics should not be interpreted as linear or instantaneous. Instead, the findings support evolutionary and path-dependence approaches, according to which sustainability-oriented transformation processes are cumulative, institutionally conditioned, and characterised by delayed adjustment mechanisms. The study also confirms the importance of analysing sustainable development dimensions simultaneously, as significant interdependencies and trade-offs may arise between economic, social and environmental objectives.

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AI-FOR-HEALTH MATURITY IN EU MEMBER STATES A WHO-INFORMED EUROSTAT ANALYSIS

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Purpose: This paper operationalizes AI-for-health maturity in EU Member States by translating WHO-informed evidence into a reproducible analytical outcome linked to harmonized Eurostat indicators.
Design/methodology/approach: A country-year panel for the EU27 covering 2021-2024 was constructed by combining a WHO-informed maturity outcome with Eurostat-based predictors capturing innovation and R&D, data capability, health-system resources and spending, and digital access and readiness. Missing values were handled using a deterministic three-stage procedure based on within-country interpolation, forward/backward fill, and year-specific EU median imputation. The analytical workflow included descriptive screening, correlation analysis, Kruskal-Wallis tests, and a cautious predictive extension using grouped cross-validation by country.
Findings: The final panel comprised 108 country-year observations, 15 numeric predictors, and two WHO-derived outcomes: a continuous maturity score and an ordinal maturity class. The strongest descriptive associations were found for innovation- and R&D-related indicators, data-system capability, digital access, and selected health-system financing variables. Several predictors were highly collinear, indicating a tightly related innovation-capacity block. Elastic Net performed best in prediction, but explained variance remained moderate.
Research limitations/implications: Limitations include the short time horizon, small sample, missingness, deterministic imputation, and an author-defined scoring procedure.
Practical implications: The workflow provides a transparent basis for benchmarking AI-for-health maturity across European health systems.
Social implications: The study may inform policy discussion on equitable digital transformation and trustworthy AI adoption in health.
Originality/value: The paper offers a replicable EU27 framework for comparative research on AI readiness in European health systems.
Keywords: AI for health; digital maturity; Eurostat; EU27; health system readiness.
Category of the paper: Research paper.

1. Introduction

Artificial intelligence (AI) is increasingly shaping how health systems plan services, allocate resources, and deliver care, while simultaneously raising challenges related to governance, ethics, responsibility, and safeguards for trustworthy adoption. Across the WHO European Region, countries differ substantially in strategic and operational context, stakeholder engagement and workforce capacity, regulatory and legal frameworks, health data governance, AI applications, and perceived barriers to uptake. While such heterogeneity is well documented in narrative reporting and country profiles, descriptive evidence is not always immediately usable for quantitative comparative analysis or for predictive modelling workflows that require harmonized, machine-readable inputs (*Artificial Intelligence for Health in the WHO European Region*, 2025).

To bridge this gap, researchers often rely on "maturity" constructs that translate complex, multi-domain system readiness into structured indicators that can be compared across units and over time(Liaw et al., 2023). Digital health capability maturity models emphasize staged development and socio-technical foundations, and they also highlight that maturity can evolve dynamically, requiring clearly defined and reproducible measurement approaches (Liaw et al., 2022). At the same time, the practical analytic value of a maturity outcome depends on linking it to harmonized predictors that capture national differences in human capital, innovation capacity, health system resources, and digital infrastructure (*Artificial Intelligence for Health in the WHO European Region*, 2025; *Artificial Intelligence Is Reshaping Health Systems: State of Readiness across the WHO European Region*, 2025).

In parallel, the regulatory environment for AI in health is rapidly evolving and increasingly salient for cross-country comparisons, particularly in Europe where legal and policy instruments shape the conditions for deployment, accountability, and risk management (Frontiers in Public Health, 2024). This makes transparent operationalization especially important: even when an outcome such as AI-for-health "maturity" is defined, results can be sensitive to indicator definitions, dimension filters (e.g., units, sectors, population groups), and data availability constraints (*Artificial Intelligence Is Reshaping Health Systems: State of Readiness across the WHO European Region*, 2025; Eurostat, 2017).

For European comparative work, Eurostat provides a particularly suitable source of candidate predictors because it disseminates standardized indicators with metadata and programmatic access through official SDMX APIs, enabling transparent extraction and reproducible data pipelines (Eurostat, 2022). Building a country–year dataset from multiple Eurostat domains nevertheless involves practical challenges, including incomplete coverage for some indicators and inconsistent availability across countries and years; documenting missingness and applying explicit inclusion rules are therefore necessary steps prior to exploratory analysis and model development (Eurostat, 2017, 2022).

This study develops a reproducible EU27 country–year dataset for 2021-2024 that combines a WHO-informed AI-for-health maturity outcome (continuous score and ordinal maturity class) with candidate predictors retrieved from Eurostat using pre-specified dimension filters to preserve cross-country comparability (*Artificial Intelligence for Health in the WHO European Region*, 2025; Eurostat, 2022). We then characterize missingness and perform exploratory data analysis (EDA) to describe distributions, outliers, correlation structure, and potential separability of maturity classes, providing a transparent methodological foundation for subsequent work on country-generalizable classification and/or regression modelling of AI-for-health maturity (Eurostat, 2017; Liaw et al., 2023).

2. Methods

Recent peer-reviewed studies that aim to explain or predict country-level outcomes increasingly rely on multi-source data integration rather than single repositories. A common methodological pattern is to construct a "hybrid" dataset by merging heterogeneous national indicators (e.g., demographics, health status, policy measures, mobility, digitalization proxies) from multiple public sources into a single analytical table, followed by feature preprocessing, missing-data handling, and predictive modelling. For example, cross-European machine-learning work on COVID-19 outcomes explicitly builds a hybrid dataset from multiple public sources and then applies a modelling pipeline (feature preprocessing, dimensionality reduction/selection, predictive modelling, and explainability) to identify the country-level drivers of observed variation across waves (Moustakidis et al., 2022).

In organizational settings, analogous "two-dataset" designs are common: authors merge an external maturity measure with independent quality or performance outcomes and then quantify associations using regression or predictive models. A recent study of hospital digital maturity illustrates this approach by linking digital maturity metrics to quality and safety outcomes, using a multi-source design where the maturity construct and the outcomes originate from different data systems, thereby increasing interpretability while also introducing integration challenges (e.g., alignment of units, time windows, and missingness across sources) (Snowdon et al., 2024).

A third methodological stream focuses on data linkage as a way to enrich analysis beyond what a single dataset can provide. European evidence on linkage between survey data and administrative registers shows that linkage can materially increase analytic value, but it comes with governance constraints, cross-country heterogeneity in identifier availability, and systematic differences in coverage—issues that mirror the practical challenges of cross-country comparability and missingness encountered in macro indicator panels (Meltzer et al., 2022). In practice, this literature motivates explicit documentation of linkage keys (or, in macro

panels, merge keys such as country and year), as well as transparent reporting of completeness and potential bias introduced by non-uniform data availability.

Finally, some quantitative policy and readiness studies explicitly evaluate and optimize AI-related policy choices using formal quantitative frameworks and multi-source inputs, reinforcing the idea that methodological credibility in this area depends on (i) transparent integration of heterogeneous indicators, (ii) explicit missing-data strategies, and (iii) reproducible preprocessing decisions that can be audited and re-run when data are updated (Zhou et al., 2025).

Taken together, these peer-reviewed methodological examples support the core design choices in this study: integrating multiple sources into a country-year panel, documenting and controlling missingness, and using reproducible preprocessing to create a modelling-ready dataset that is suitable for comparative analysis and subsequent predictive workflows.

2.1. Datasets and scope.

We constructed a country-year panel for 27 EU Member States covering 2021-2024, combining an outcome variable derived from WHO-related digital health maturity evidence with candidate predictors retrieved from Eurostat. The architecture is shown in Figure 1.

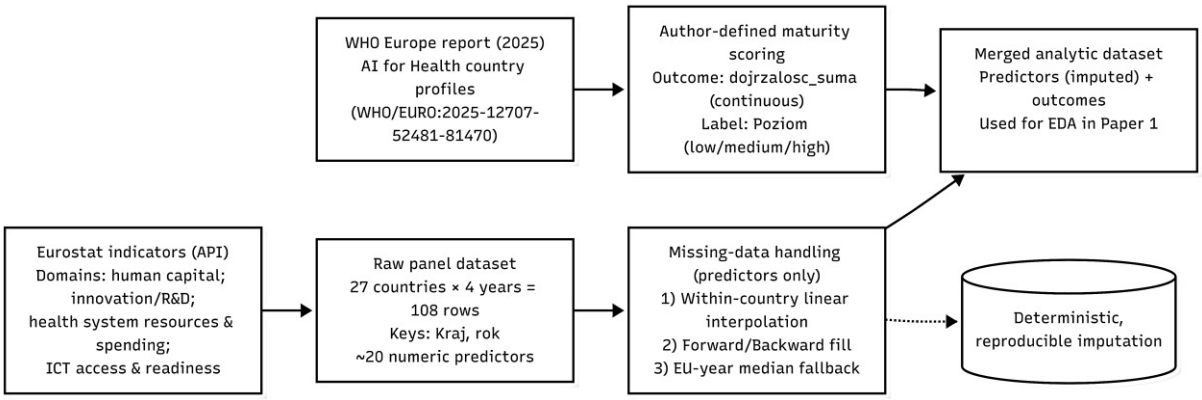

Figure 1. Data construction workflow for the analytic dataset, from WHO-based AI maturity scoring and Eurostat predictors to imputation and final dataset assembly.

Source: Own work.

Outcome definition (WHO-based maturity). Digital health maturity was operationalized as (i) a continuous score (*dojrzalosc_suma*) computed using an author-defined scoring procedure applied to WHO-sourced maturity evidence, and (ii) an ordinal class label (*Poziom*: low/medium/high) obtained by thresholding the score according to pre-specified cut-offs.

The WHO classification, which includes three stages of artificial intelligence institutionalization—informal adoption, pilot implementation, and established use—was applied. For each country, the indicator was calculated as the weighted sum of the number of AI applications assigned to these categories, with weights of 1 for informal adoption, 2 for pilot implementation, and 3 for established use. This operationalization made it possible to capture

both the scale of AI use and the degree of its institutional embedding within the healthcare system.

Subsequently, based on the obtained index values, countries were classified according to three levels of AI implementation maturity: low, medium, and high. Compared to a binary classification, this three-category approach allows for a more nuanced presentation of differences between countries by distinguishing not only between systems with low and high levels of maturity but also an intermediate category of countries occupying a middle position in terms of the advancement of AI implementation.

Predictor selection (Eurostat). Predictor variables were selected a priori to cover human capital, innovation/R&D, health system resources and spending, and ICT access and readiness, and were extracted from Eurostat using fixed dimension filters (e.g., unit, sector, age/sex) to ensure cross-country comparability.

Data access and reproducibility. Eurostat data and metadata can be accessed programmatically via the Eurostat dissemination API; dataset codes and filters are reported to ensure reproducibility.

Dataset overview (EU27, 2021-2024)

We constructed a country-year panel for the 27 EU Member States covering 2021-2024, combining a WHO-informed AI-for-health maturity outcome with candidate predictors retrieved from Eurostat. The analytical objective was to create a reproducible dataset suitable for descriptive screening, between-class comparison, and cautious predictive modelling of AI-for-health maturity across countries.

Digital health maturity was operationalized as (i) a continuous score (*dojrzalosc_suma*) derived from WHO-informed evidence and (ii) an ordinal class label (*Poziom*: low, medium, high) obtained using pre-specified thresholds. The WHO-based operationalization applied a weighted scoring logic reflecting three stages of AI institutionalization in health systems: informal adoption, pilot implementation, and established use.

Predictor variables were selected a priori to represent innovation and R&D, data capability, health-system resources and spending, and digital access. Eurostat indicators were extracted using fixed dimension filters to preserve cross-country comparability and reproducibility.

The final analytical panel retained 15 numeric predictors:

- *Otoczenie_innowacyjne_i_BR*, *Presja_popytowa*.
- *Zdolnosc_systemowa_dane*.
- *System_ochrony_zdrowia*.
- *Wydatki_firm_na_BR_BERD_wedlug_dzialalnosci*.
- *GERD_sektor_i_dziedziny_BR*.
- *GERD_sektor_i_rodzaj_instytucji*.
- *Lata_zycia_w_zdrowiu_HLY*.
- *Lozka_szpitalne_wedlug_regionow*.

- *Urzadzenia_do_obrazowania_medycznego*.
- *Wydatki_na_opieke_zdrowotna_wedlug_dostawcow*.
- *Wydatki_przedsiebiorstw_BR_zaawansowane_technologie*.
- *Wydatki_przedsiebiorstw_BR_sektor_ICT*.
- *Dostep_do_internetu_gospodarstwa_domowe*,
- *Urzadzenia_do_dostepu_do_internetu_osoby*.

Four candidate variables were excluded before the final analytical panel was assembled: *Poziom_wdrozenia_AI_w_firmach*, *Analityka_danych_wedlug_dzialalnosci*, *Zatrudnienie_w_sektorach_tech_i_wiedzy*, and *Bezpieczenstwo_ICT_polityka_srodki_ryzyko_swiadomosc*. In the final imputed dataset, no missing values remained across the retained analytical variables.

Before imputation, however, missingness varied substantially across retained predictors. The highest pre-imputation missingness among retained variables was observed for *Urzadzenia_do_dostepu_do_internetu_osoby* (55.6%), *Wydatki_przedsiebiorstw_BR_zaawansowane_technologie* (54.6%), *Wydatki_przedsiebiorstw_BR_sektor_ICT* (42.6%), and *Lozka_szpitalne_wedlug_regionow* (38.0%), while several other retained variables showed lower but non-negligible incompleteness.

The retained variables and their pre-imputation missingness are summarized in Table 1. This distinction between the pre-imputation candidate panel and the final imputed analytical panel is important for interpreting both the completeness diagnostics and the subsequent modelling results.

Table 1.
Missingness table -Missing % = NA_in_108 / 108 × 100.

variable	***n***	***%***
Urzadzenia_do_dostepu_do_internetu_osoby	**60**	**55.6**
Wydatki_przedsiebiorstw_BR_zaawansowane_technologie	**59**	**54.6**
Bezpieczenstwo_ICT_polityka_srodki_ryzyko_swiadomosc	**54**	**50.0**
Wydatki_przedsiebiorstw_BR_sektor_ICT	**46**	**42.6**
Lozka_szpitalne_wedlug_regionow	**41**	**38.0**
Lata_zycia_w_zdrowiu_HLY	**28**	**25.9**
Urzadzenia_do_obrazowania_medycznego	**27**	**25.0**
Poziom_wdrozenia_AI_w_firmach	**27**	**25.0**
System_ochrony_zdrowia	**27**	**25.0**
Wydatki_na_opieke_zdrowotna_wedlug_dostawcow	**27**	**25.0**
Dostep_do_internetu_gospodarstwa_domowe	**5**	**4.6**
Zdolnosc_systemowa_dane	**2**	**1.9**
Zatrudnienie_w_sektorach_tech_i_wiedzy	**2**	**1.9**

Source: Own elaboration.

Data gaps are mainly due to incomplete reporting for certain years/countries and the need to apply harmonized filter settings (e.g., entity, sector, indicator) to ensure comparability between Member States. For some indicators on digitization and ICT security, data availability is limited to subsets of countries/years, leading to a higher number of gaps.

2.2. Missing data & imputation

Missingness handling. Missing values in predictors were handled using a deterministic, three-stage procedure applied within each country over time: (1) linear interpolation, (2) forward/backward fill, and (3) year-specific EU median imputation as a fallback.

$$\hat{x}_{c,t} = \begin{cases} x_{c,t_0} + \frac{x_{c,t_1} - x_{c,t_0}}{t_1 - t_0}(t - t_0), & \text{if there exist } t_0 < t < t_1 \text{ and } x_{c,t_0}, x_{c,t_1} \text{ are observed,} \\ x_{c,t^-}, & \text{if interpolation is not possible and there exists } t^- < t \text{ with observed } x_{c,t^-} \text{ (forward fill),} \\ x_{c,t^+}, & \text{if interpolation and forward fill are not possible and there exists } t^+ > t \text{ with observed } x_{c,t^+} \text{ (backward fill),} \\ \text{median}_{c' \in EU}\left(x_{c',t}\right), & \text{otherwise (fallback: EU median in year } t\text{).} \end{cases} \quad (1)$$

Where c denotes the country and t the year; t_0 and t_1 are the nearest observed years bracketing the missing value within country c, t^- is the closest earlier observed year, and t^+ is the closest later observed year.

3. Results

The analytical dataset comprised 108 country-year observations for the EU27 in 2021-2024, including 15 numeric Eurostat predictors and two WHO-derived outcomes: the continuous maturity score "*dojrzalosc_suma*" and the ordinal maturity class "*Poziom*". Integrity checks identified no duplicate country-year rows and no missing cells after preprocessing, which indicates that the final analytical panel was internally consistent and complete for the reported analyses. The distribution and balance of classes are shown in Figure 2.

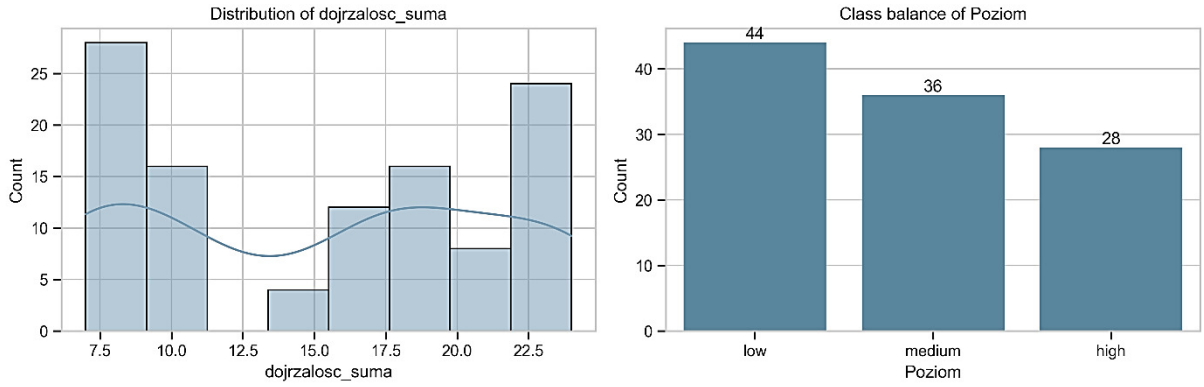

Figure 2. Targets overview.

Source: Own work.

The ordinal outcome was moderately imbalanced, with 44 observations classified as low maturity (40.7%), 36 as medium maturity (33.3%), and 28 as high maturity (25.9%). This distribution shows that the panel covered the full maturity spectrum, while low- and medium-maturity observations remained more common than high-maturity cases. Table 2 shows the best predictors according to Spearman's and Pearson's correlations.

Table 2.
Top predictors

Variable	spearman_r	pearson_r
Otoczenie_innowacyjne_i_BR	0,51	0,47
Presja_popytowa	0,51	0,47
Wydatki_firm_na_BR_BERD_wedlug_dzialalnosci	0,51	0,47
GERD_sektor_i_dziedziny_BR	0,51	0,47
Zdolnosc_systemowa_dane	0,47	0,26
Dostep_do_internetu_gospodarstwa_domowe	0,45	0,37
Wydatki_na_opieke_zdrowotna_wedlug_dostawcow	0,44	0,47
System_ochrony_zdrowia	0,42	0,40
GERD_sektor_i_rodzaj_instytucji	0,41	0,00
Wydatki_przedsiebiorstw_BR_zaawansowane_technologie	0,41	0,00
Lata_zycia_w_zdrowiu_HLY	-0,33	-0,35
Lozka_szpitalne_wedlug_regionow	0,31	0,33
Urzadzenia_do_dostepu_do_internetu_osoby	0,25	0,25
Wydatki_przedsiebiorstw_BR_sektor_ICT	0,10	0,22
Urzadzenia_do_obrazowania_medycznego	0,09	0,15

Source: Own work.

Descriptive screening showed that the strongest monotonic associations with the continuous maturity score were observed for a cluster of innovation and R&D-related indicators, including *Otoczenie_innowacyjne_i_BR*, *Presja_popytowa*, *Wydatki_firm_na_BR_BERD_we dlug_dzialalnosci*, and *GERD_sektor_i_dziedziny_BR* (all Spearman $r = 0.510$), followed by *Zdolnosc_systemowa_dane* (Spearman $r = 0.466$). Additional positive associations were observed for *Dostep_do_internetu_gospodarstwa_domowe*, *Wydatki_na_opieke_zdrowotna_wedlug_dostawcow*, and *System_ochrony_zdrowia*, suggesting that innovation capacity, data-system capability, digital access, and selected health-system financing indicators aligned with higher maturity scores in descriptive terms.

Between-class comparisons further supported this pattern. The largest class differences by Kruskal–Wallis screening were observed for:

- *Wydatki_na_opieke_zdrowotna_wedlug_dostawcow* ($H = 30.44$).
- *Otoczenie_innowacyjne_i_BR* ($H = 27.99$).
- *Presja_popytowa* ($H = 27.99$).
- *Wydatki_firm_na_BR_BERD_wedlug_dzialalnosci* ($H = 27.99$).
- *GERD_sektor_i_dziedziny_BR* ($H = 27.99$).
- *Zdolnosc_systemowa_dane* ($H = 26.32$).

indicating that these variables most clearly differentiated low-, medium-, and high-maturity observations. The differences between the classes are shown in Figure 3.

At the same time, the predictor correlation matrix showed substantial redundancy among several retained variables. In particular, some innovation and R&D indicators were perfectly rank-correlated in the current panel, including *Otoczenie_innowacyjne_i_BR, Presja_popytowa, Wydatki_firm_na_BR_BERD_wedlug_dzialalnosci, and GERD_sektor_i_dziedziny_BR* ($r = 1.000$), which suggests that the descriptive signal was partly concentrated in a tightly collinear predictor block rather than in fully independent dimensions. Table 3 shows the complete results.

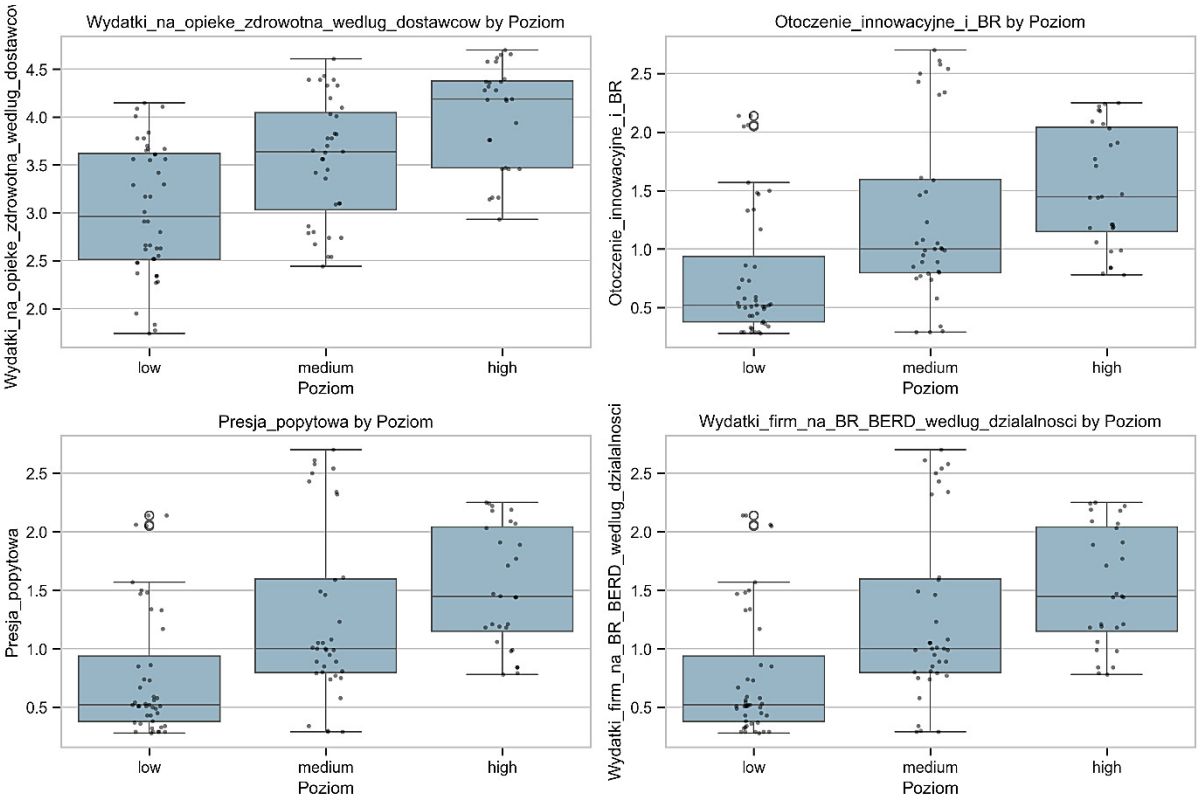

Figure 3. Top boxplots by outcome.

Source: Own work.

Table 3.
Group differences by maturity class

variable	kruskal_H	kruskal_p
Wydatki_na_opieke_zdrowotna_wedlug_dostawcow	30,44	0,00000
Otoczenie_innowacyjne_i_BR	27,99	0,00000
Presja_popytowa	27,99	0,00000
Wydatki_firm_na_BR_BERD_wedlug_dzialalnosci	27,99	0,00000
GERD_sektor_i_dziedziny_BR	27,99	0,00000
Zdolnosc_systemowa_dane	26,32	0,00000
System_ochrony_zdrowia	23,93	0,00001
GERD_sektor_i_rodzaj_instytucji	22,75	0,00001
Wydatki_przedsiebiorstw_BR_zaawansowane_technologie	22,75	0,00001
Dostep_do_internetu_gospodarstwa_domowe	15,46	0,00044
Lata_zycia_w_zdrowiu_HLY	11,63	0,00298
Lozka_szpitalne_wedlug_regionow	7,27	0,02639
Urzadzenia_do_dostepu_do_internetu_osoby	6,38	0,04121
Urzadzenia_do_obrazowania_medycznego	5,76	0,05610
Wydatki_przedsiebiorstw_BR_sektor_ICT	1,94	0,37877

Source: Own work.

As a cautious predictive extension, grouped cross-validation by country was used to test (e.g., Table 4) whether the retained predictors contained out-of-country signal for the continuous maturity score. Among the evaluated regression models, Elastic Net performed best, with MAE = 4.337 and RMSE = 5.230, outperforming both Ridge and the baseline mean model; however, the explained variance remained modest ($R^2 = 0.297$), indicating partial but limited predictive generalisability across countries.

Table 4.
Grouped regression modelling

	model	MAE	RMSE	R2
0	ElasticNet	4.336912	5.230291	0.297355
1	Ridge	4.452667	5.284934	0.282596
2	Baseline mean	5.921998	6.665395	-0.141133

Source: Own work.

The partial predictive fit between the observed and predicted values is shown in Figure 4.

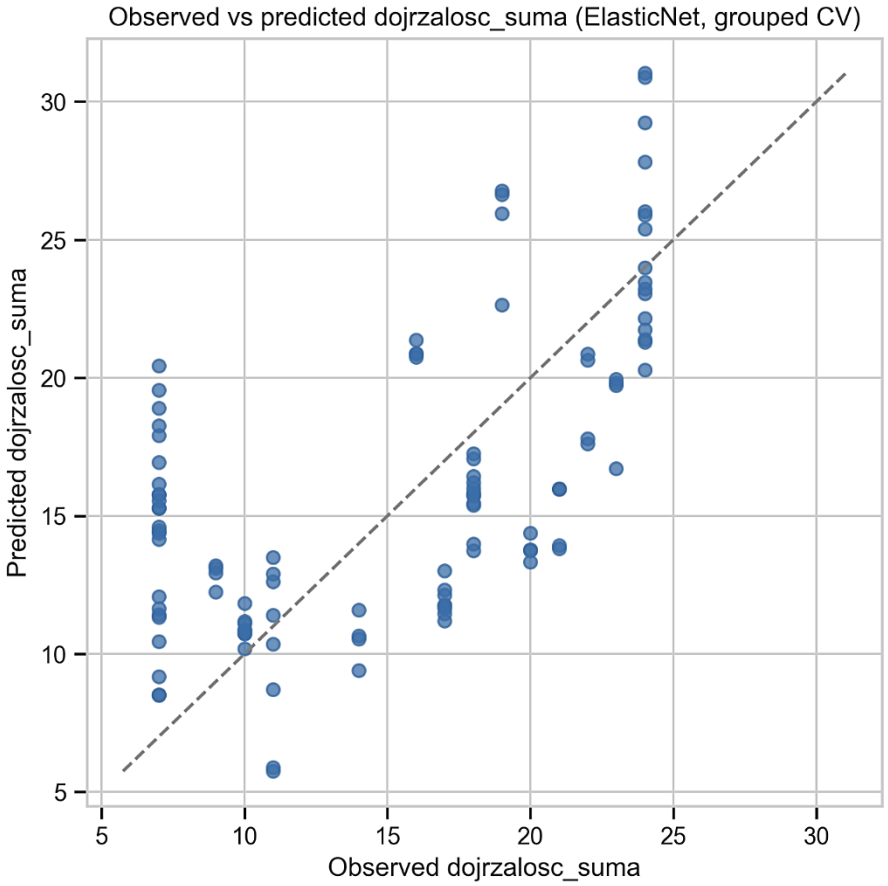

Figure 4. Regression-observed vs predicted.

Source: Own work.

The observed-versus-predicted plot suggested a possible non-linear pattern, particularly at the lower and upper ends of the outcome range; however, polynomial extensions did not improve grouped cross-validated performance over ElasticNet or Ridge. Therefore, the apparent curvature was treated as a useful diagnostic signal rather than sufficient evidence to replace the main linear specification.

4. Discussion

The present findings should be interpreted within a wider body of research showing that digital maturity in health care is a multidimensional construct that extends beyond infrastructure and software availability. Recent work on digital health communication maturity, data and AI governance, and national hospital maturity assessment indicates that meaningful readiness depends on organizational capability, interoperability, communication processes, implementation routines, and governance structures (Cresswell et al., 2025; Kim, Namkoong, 2025; Morley et al., 2022).

From this perspective, the strong descriptive role of innovation- and R&D-related indicators is consistent with comparative research suggesting that AI maturity is embedded in broader ecosystem capacity. Cross-country analysis of OECD health systems argues that countries differ not only in their rate of adoption but also in the maturity of their policy, strategic, and implementation environments, while OECD policy work similarly emphasizes that scaling AI in health requires system-level preparedness rather than isolated pilots or fragmented projects (Castonguay et al., 2024).

The importance of data capability and digital access in the present analysis is also closely aligned with previous maturity and interoperability research. The Health Information Systems Interoperability Maturity Toolkit and its application in Kenya illustrate that digital initiatives may coexist with relatively weak operational interoperability, which helps explain why macro-level readiness varies substantially across settings and why information exchange remains a limiting factor in many systems (Evaluation, 2017; Nyangena et al., 2021). Related international frameworks from the World Bank and the Global Digital Health Partnership likewise position data exchange, standards, and implementation governance as core dimensions of digital maturity assessment (World Bank, n.d.; World Health Organization, n.d.)

The present results are also compatible with hospital-level evidence indicating that digital advancement tends to be uneven across dimensions. Findings from the German DigitalRadar show that maturity may be stronger in structures and systems than in patient participation, telemedicine, or exchange of information, which suggests that digital transformation is layered rather than uniform (Geissler et al., 2024). Similar conclusions emerge from comparative work on national approaches to assessing hospital digital maturity and from systematic reviews of hospital maturity dimensions, both of which describe digital development as internally differentiated and only partly synchronized across organizational domains(Cresswell et al., 2025; Nurhayati et al., 2025).

This interpretation is further reinforced by telemedicine and telehealth maturity research. Existing models of telemedicine service maturity conceptualize maturity as staged organizational development involving workflow integration, leadership support, service design, and long-term scaling capacity rather than as the simple presence of remote technologies

(Development of a Maturity Model for Telemedicine Services, 2024; Ingenium Digital Health, 2021; van Dyk, Schutte, 2013). Evidence from the Brazilian telehealth maturity model reaches a similar conclusion by showing that institutional diagnostics are needed before maturity can be meaningfully assessed, which supports the view that readiness is deeply embedded in organizational context (Silva et al., 2024).

At the same time, the present findings should not be taken to mean that general digital maturity is equivalent to AI-specific readiness. Work on data and AI governance in health care has shown that trustworthy AI deployment requires explicit arrangements for accountability, stewardship, oversight, and institutional responsibility, while broader OECD analyses stress the importance of evaluation, policy alignment, and implementation safeguards for scaling AI safely in practice (Morley et al., 2022; Organisation for Economic Co-operation & Development, 2026). This distinction is reinforced by recent discussions of digital maturity as a possible but incomplete gatekeeping concept for health AI, as well as by work arguing that accreditation-linked requirements may help build the organizational foundations needed for effective AI adoption (As'ad, Faran, 2025; Bellei et al., 2026).

The observed concentration of signal within an innovation-related block is therefore theoretically plausible. Previous maturity research suggests that governance, infrastructure, communication capability, interoperability, and organizational routines frequently co-evolve, meaning that empirical studies often capture a broader latent readiness dimension rather than a set of fully independent mechanisms (Global Digital Health Partnership, 2026; Kim, Namkoong, 2025; Mapping Digital Health Maturity Models and Accreditation-Linked Standards, 2025). From that perspective, multicollinearity may reflect substantive interdependence among readiness domains rather than only a technical modelling issue.

The moderate predictive generalizability observed in this type of work also supports a cautious interpretation of explanatory models. Differences in framework scope, indicator design, implementation context, and data completeness make strong out-of-sample prediction difficult across heterogeneous health systems, even when descriptive structures remain informative (As'ad, Faran, 2025; Cresswell et al., 2025; World Bank, n.d.). For this reason, maturity-oriented models may be especially valuable as strategic and comparative tools, whereas their predictive performance should be interpreted with methodological caution.

Overall, the present study fits a literature showing that AI-for-health readiness is embedded in broader national capabilities related to innovation, interoperability, implementation maturity, and governance. Future research would benefit from extending macro-level models with more explicit indicators of standards, accreditation, patient participation, safety capability, and AI-specific oversight so that digital maturity and AI readiness can be distinguished more clearly in comparative health-system research (Geissler et al., 2024; Kutza et al., 2022).

5. Conclusion

This study developed a reproducible EU27 country-year dataset that combines a WHO-informed AI-for-health maturity measure with harmonized Eurostat predictors for 2021-2024. The results show that the constructed panel is analytically coherent and that AI-for-health maturity is descriptively associated with innovation and R&D capacity, data-system capability, digital access, and selected health-system financing indicators.

At the same time, the modelling results indicate only moderate predictive generalizability part across countries. For that reason, the predictive component should be interpreted as a transparent proof-of-concept rather than a final forecasting benchmark.

The main contribution of the paper is therefore methodological as much as substantive. By operationalizing a WHO-informed maturity construct and embedding it in a reproducible Eurostat-based workflow, the study provides a practical basis for future comparative analyses of AI readiness in European health systems.

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Appendix/Supplementary Material

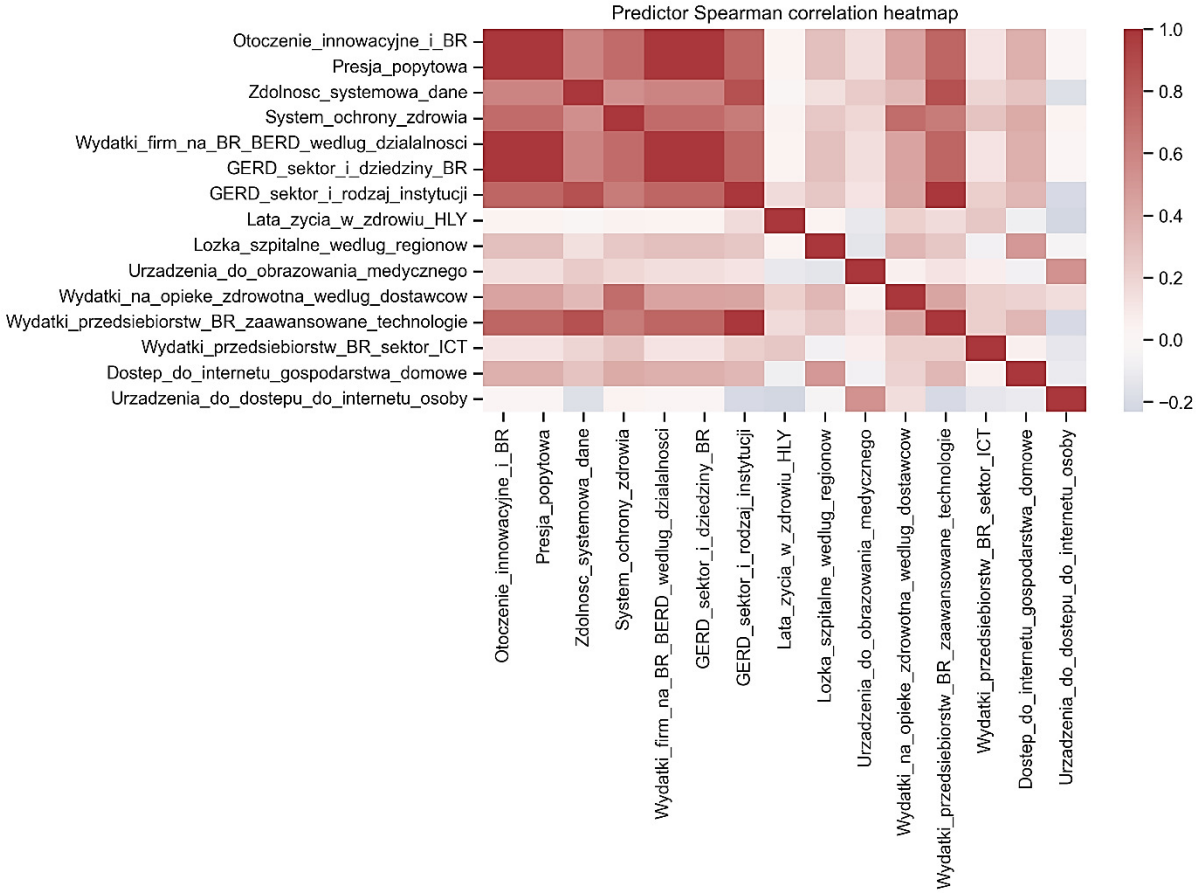

Figure 5. Spearman correlation heatmap.

Source: Own work.

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THE IMPACT OF REVERSE LOGISTICS PROCESSES ON THE RESIDUAL VALUE OF ELECTRIC VEHICLES UNDER OPERATING LEASES

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Objective: The aim of this article is to examine the impact of battery degradation and reverse logistics processes, including the concept *of Shared Reverse Logistics* (SRL), on the residual value (*RV*) of electric vehicles (*EVs*) under operating leases. The analysis focuses on the relationships between the battery capacity degradation path (*State of Health – SoH*), battery management after the end of its first life, and the dynamics of the EV secondary market.
Project/methodology/approach: The study, based on a review of the literature on battery degradation, reverse logistics and the second life of cells, using an analytical-synthetic approach, demonstrates how the rate of degradation and economic and organisational factors shape the residual value of EVs. The analysis links physicochemical processes in batteries with their implications for business models, operating costs and risk management in leasing.
Results: The analysis revealed that battery degradation and the lack of standardisation of SoH increase residual risk, whilst return logistics and the SRL concept influence costs and value recovery. The growing importance of the battery passport and standardised SoH reporting may improve the transparency and stability of vehicle valuation at the end of the lease.
Limitations/implications of the research: The research limitations stem from the variety of methods used to measure SoH and the lack of uniform standards, which hinders data comparability and the drawing of clear conclusions. A need for further research has been identified regarding the cost-effectiveness of SRL, RV prediction models based on real-world data, and the impact of EU regulations on the leasing market and risk management.
Practical implications: Research indicates that leasing and fleet companies must mitigate EV residual risk by standardising SoH diagnostics, developing reverse logistics centres, and incorporating the costs of battery second life and recycling into RV valuation. Collaboration with manufacturers regarding access to battery data is key.
Social implications: Research shows that effective EV battery return logistics strengthens the circular economy, increases recycling and component recovery, and reduces environmental pressure. At the same time, it raises standards of corporate social responsibility and influences the direction of public policy in the areas of sustainable transport and waste management.
Originality/value: The article integrates three areas of research: battery degradation, reverse logistics organisation, and mechanisms for determining residual value. An innovative aspect is the inclusion of SRL and the emphasis on the role of the battery passport. The article as a whole provides a coherent perspective for companies, manufacturers, regulators and researchers.
Keywords: electric vehicles, lithium-ion batteries, reverse logistics, operating lease, residual value.
Category of the paper: Literature review, general overview.

1. Introduction

The dynamic growth in the share of electric vehicles (*EVs*) in Europe and worldwide is leading to a significant change in the structure of economic risk within the automotive sector. In traditional internal combustion engine vehicles, the main risks were associated with the operation of the engine and drivetrain, whereas in electric vehicles the traction battery becomes a key component, accounting for 30-40% of the vehicle's value. In the case of fleet financing via operating leases, this means that the residual value (*RV*) is increasingly determined by the condition of the battery, its expected degradation, and the possibilities for its reuse at the end of its first life (Szymańska, 2026; Voltowa.com, 2026).

Unlike internal combustion engine vehicles, for which depreciation curves are well-documented based on long-term market data, the residual value of an EV is strongly correlated with *the* battery's *State of Health (SoH*). The degradation of lithium-ion batteries is both calendar-based and cyclic, and its rate depends on a number of factors: operating temperature, depth of discharge (*DoD*), charging rate, cell chemistry and environmental conditions. A review of the literature indicates that key degradation mechanisms include, among others, electrolyte decomposition, increased internal resistance, side reactions, and structural changes in cathode and anode materials (Lisiak, 2026).

Experimental studies confirm that LFP achieves up to 5293 cycles at 25^0 C and a low current of C/20, which significantly exceeds the stability of NMC and NCA batteries under the same conditions. At the same time, fast charging (DC[1] fast charging) can accelerate degradation by 10-15% compared to slow charging, and exposure to temperatures above 40^0 C can increase the rate of degradation by up to three times. In market practice, it is accepted that a threshold of 70-80% SoH marks the limit of a battery's full usability in traction applications. Below this level, the vehicle loses some of its functionality (range, dynamics), which directly reduces its residual value. Manufacturers usually guarantee that≥ 70–80% of capacity will be maintained for 8 years, a claim supported by market data covering over a million vehicles (Elektrowoz.pl, 2026).

In the context of the growing number of electric vehicles, it is crucial from both an environmental and economic perspective to focus on return logistics models that take into account operating leases and changes in the residual value of vehicles. The article proposes three general reverse logistics models, highlighting the complexity of the relationships and possible options for handling electric vehicles after the lease period.

At the same time, the importance of battery reverse logistics (*RL*) is growing, encompassing collection, transport, storage, dismantling, diagnostics, regeneration, preparation for *a* second life, and recycling. The design of RL networks is being intensively researched in the context

[1] DC – Direct Current.

of: the location of collection and recycling centres, the optimisation of material flows, the assessment of economic viability, and the reduction of the environmental footprint (Sadowski, 2010). The concept of Shared Reverse Logistics (SRL) is appearing with increasing frequency in the literature, in which manufacturers, fleet operators and logistics companies share infrastructure, thereby reducing costs and increasing environmental efficiency. The residual value of an electric vehicle under an operating lease is therefore the result of a complex interaction between the battery degradation path over the lease term (SoH -> range -> usability), the potential for battery utilisation after the lease ends (second life, recycling, material recovery), and the market situation in the EV secondary market, including demand for used vehicles and the perception of technological risk (Lygizos, Kastanaki, Giannis, 2025).

The remainder of the article analyses the relationship between reverse logistics processes and the determination of the residual value of electric vehicles under operating leases. Particular attention is paid to issues relating to the degradation of traction batteries, technical diagnostics, remarketing processes, and the potential for reusing batteries in a second-life model. Original process and system models are also presented, illustrating the impact of reverse logistics organisation on mitigating the lessor's economic risk.

2. The impact of battery degradation on the residual value of EVs

The literature on lithium-ion battery degradation in electric vehicles discusses both physicochemical models and empirical and probabilistic approaches. M.N. Akram and W. Abdul-Kader analyse changes in the condition of EV batteries using Markov chain models[2] , distinguishing between the following states: new, reconditioned, second-life and recycling. This allows not only for the prediction of battery lifespan, but also for the share of individual disposal pathways in the long term, which is of direct relevance to the planning of reverse logistics and raw material recovery (Akram, Abdul-Kader, 2021).

The residual value of electric vehicles is determined to a much greater extent by the condition of the traction battery than in the case of internal combustion engine vehicles, where the main determinants are mileage, age and service history. Battery degradation directly affects range, performance and the perceived risk of purchase on the secondary market. Market research and analysis indicate that both the perception of risk and actual data on SoH decline, as well as manufacturers' warranties, shape the level of residual value across different market segments.

[2] A Markov model is a stochastic method for randomly changing systems, in which it is assumed that future states do not depend on past ones. These models show all possible circumstances, as well as transitions, their rates and the probabilities between them. Source: Business Insider, *Markov model – what is it and what are its applications?* Retrieved from: https://businessinsider.com.pl/gospodarka/makroekonomia/model-markowa-definicja-typy-i-zastosowanie/6czkt2x, 04/04/2026).

EV lessors and financing institutions are exercising increased caution in assessing residual value, mainly due to uncertainty regarding the condition of the battery after 3-5 years of use. This stems from two factors. The first is the lack of uniform standards for measuring SoH. The measurement of State of Health, a key indicator determining the remaining usable battery capacity, is not currently standardised. Different manufacturers use varying methods to estimate SoH, based on mathematical models, impedance measurements, analysis of charging cycles, or machine learning algorithms. A review of the literature indicates that the non-linear nature of degradation and its dependence on usage conditions make it difficult to establish a single, universal diagnostic standard. The lack of consistent measurement methods means that lessors cannot unequivocally assess the risk associated with the value of the battery at the end of the lease agreement. As a result, they apply conservative residual value (RV) assumptions, often underestimating the value of electric vehicles relative to their actual lifespan (EV Klub Polska, 2026).

Another factor is the uncertainty regarding the rate of degradation after several years of electric vehicle use. There is a persistent narrative in the public sphere about the rapid ageing of batteries, which exacerbates financiers' concerns. However, a report by P3 Group (Hackman, Knörzer, Pfeuffer, Jeckel, 2024), based on an analysis of over 7000 vehicles, indicates that the actual rate of degradation is significantly lower than suggested by media reports, and that batteries retain high capacity even after several years of use. Nevertheless, the perception of risk remains high, which leads to caution in calculating residual value (Voltowa.com, 2026).

Market data from analyses of over 58,000 EV listings show that the difference between a vehicle with an SoH of 92% and 75% can mean a 30-40% reduction in real-world range and a difference of up to $6000 in the market value of a used vehicle. This means that battery degradation is one of the strongest factors influencing the price of EVs on the secondary market (Evdlaciebie.pl (a), 2026; DatGroup, 2026).

It is worth noting that SoH affects not only range but also the perceived risk of future costs, such as the need to replace a module or the entire battery. Therefore, buyers prefer vehicles with a documented battery condition, as confirmed by data showing that cars with an SoH report sell faster (21 days vs. 39 days) (Luo, Huang, 2025).

The urban vehicle segment (small batteries, lower purchase price) shows greater sensitivity to SoH degradation. This is because a smaller battery results in a greater percentage drop in range for the same loss of capacity. Furthermore, users in this segment are more likely to use fast charging, which can accelerate degradation, and buyers in this segment are more price-sensitive. In contrast, the premium segment is characterised by larger batteries that degrade more slowly (e.g. Tesla Model S/X: 12% degradation after 200,000 miles), higher buyer tolerance for a reduction in range, and better service documentation and availability of SoH reports. As a result, premium vehicles retain a higher residual value, and battery degradation has a relatively smaller impact on them (Evdlaciebie.pl (b), 2026; Premium Autos Inc., 2026).

Despite the stabilising effect of warranties, there are areas where their scope is perceived as insufficient, as warranties do not cover degradation resulting from improper use (e.g. frequent charging to 100%), do not always cover the costs of replacing individual modules if the SoH of the entire pack does not fall below a threshold, do not account for differences in SoH between vehicle segments, and do not resolve the issue of a lack of standardisation in SoH measurement. As a result, warranties stabilise RV but do not completely eliminate the risk for lessors and buyers.

3. Return logistics in operating leases – role and challenges

Return logistics in the operational leasing of electric vehicles is a key element of a business model based on access to a service (*product-service system*), in which the user operates the vehicle whilst ownership of the asset remains with the lessor. Its primary function is to ensure the controlled, safe and economically viable 'return' of the vehicle and battery to the value chain upon contract expiry through remarketing, refurbishment, reuse or recycling. In the literature, reverse logistics is defined as the systematic planning, execution and control of the flow of materials, information and value from the user or the disposal of the product (Lygizos, Kastanaki, Giannis, 2025; Mahboubi, Kazemi Miyangaskary, Keivanpour, Lamghari, 2025).

In the context of EVs, operating leases highlight the importance of reverse logistics for two reasons. Firstly, it is the lessor who bears the ultimate risk regarding the residual value of the vehicle and the battery, and is therefore directly interested in accurate diagnostics of the technical condition and the optimal choice of a path for further use. Secondly, the growing volumes of batteries nearing the end of their useful life necessitate the design of specialised logistics networks, encompassing collection, testing, storage, transport, and regeneration and recycling processes in accordance with the principles of *the circular economy* (Almuwallad, 2026).

As a result, reverse logistics in EV operating leases is becoming not merely a support function, but a strategic area of risk, cost and sustainability management that combines financial (residual value), technical (battery and vehicle condition), regulatory (safety, ADR, environmental regulations) and market (demand for used vehicles and 'second-life' batteries). From an operational perspective, return logistics in EV operating leases begins upon the expiry of the operating lease agreement and involves an organised process for collecting the vehicle from the user. This involves planning the date and location of return, verifying the completeness of the equipment, a preliminary visual assessment of the vehicle's condition, as well as formal confirmation of the lessor or logistics operator assuming responsibility for the vehicle. In the case of EVs, this process is more complex than for internal combustion engine vehicles,

as it requires consideration of specific safety requirements related to high voltage, potential thermal damage, and the need to ensure appropriate storage and transport conditions for the traction battery (Wenzhu Liao, Luo, 2022; Gonzales-Calienes, Yu, Bensebaa, 2022).

In practice, a model is increasingly being adopted whereby vehicle collection is carried out by a specialised reverse logistics operator acting on behalf of the lessor. This operator is responsible for organising transport to a remarketing centre or battery centre, ensuring compliance with ADR regulations, and recording vehicle and battery data in IT systems (*traceability*). Solutions of this type are being developed, among others, by global 3PL operators who are building dedicated networks for EV batteries and end-of-life vehicles (e.g. the network of 'Battery Logistics Centres' in Europe) (Mishra, Apte, Dhok, 2025; Chen, 2025).

From the perspective of the lessor and the reverse logistics operator, this information enhances the reliability of battery condition assessments, enabling the interpretation of SoH test results in the context of actual operation, and allows for the segmentation of returned vehicles (e.g. city fleets, long-distance fleets, car-sharing), which facilitates the selection of an appropriate remarketing strategy and further use of the batteries. Furthermore, it can form the basis for shaping contractual policies (e.g. fast-charging limits, operational recommendations), which mitigate the risk of excessive battery degradation in advance (Sadowski, 2022).

The literature on reverse logistics and the sharing economy emphasises that operational data is a key resource enabling the design of sustainable business models in which value is co-created by multiple stakeholders, and decisions regarding the recovery and reuse of resources are based on reliable information (Mahboubi, Kazemi Miyangaskary, Keivanpour, Lamghari, 2025).

4. The impact of reverse logistics on the residual value of electric vehicles

Reverse logistics in the electric vehicle segment involves the organised flow of the vehicle and its key components (in particular the traction battery) from the end user back to primary market entities or specialised operators, for technical assessment, regeneration, reuse or recycling. Its quality and maturity directly translate into the level of uncertainty regarding the vehicle's technical condition, and thus into the determination of residual value, which forms the basis for calculating lease instalments, remarketing decisions and risk assessment by financing institutions. In the case of electric vehicles, the condition of the traction battery is of particular importance, as described by the SoH indicator, which defines the ratio of current usable capacity to factory capacity and is one of the main determinants of value on the secondary market. Fleet studies (including Arval, Geotab, P3, Aviloo) show that battery

degradation is generally slower than consumers fear, which creates the potential to build higher residual value provided that reliable diagnostics and transparent documentation of the vehicle's operating history are ensured (Michalak, 2026).

Return logistics is therefore becoming not only a technical and operational process, but also a tool for information and risk management. The better organised the flow of data on the battery and the vehicle (SoH tests, battery passport, charging history, repairs and complaints), the lower the risk premium required by the secondary market and financing institutions, and thus the higher the residual value that can be maintained (Lysenko-Ryba, 2015).

Transparency of the logistics process during the vehicle return phase is crucial for reducing information asymmetry between the seller (lessor, fleet operator, dealer) and the buyer in the secondary market. In practice, this boils down to two interrelated elements: (1) standardisation of diagnostic procedures, in particular SoH tests, and (2) ensuring the continuity and reliability of documentation (e.g. battery passport, reports from independent tests). The SoH indicator, although conceptually simple, can be determined using various methods, ranging from BMS readings to external load tests and voltage-time curve analyses (Piaskowski, 2026).

Incorporating standardised SoH tests into the reverse logistics process as a mandatory step when returning a vehicle from a lease, terminating a fleet contract or accepting a car in part exchange reduces buyer uncertainty by providing an objective battery health indicator that is comparable over time and across models, facilitate valuation by linking SoH ranges to residual value tables (e.g. separate RV curves for SoH≥ 90%, 80-89%, <80%) and limit the scope for abuse by sellers, as an independent, certified test becomes a market standard and its absence serves as a warning sign. In the literature and market practice, the role of independent tests (e.g. Aviloo, TÜV Battery Check) is increasingly highlighted as 'certificates of trust' for the secondary market, analogous to accident reports or service histories in combustion engine vehicles (Autocentrum Editorial Team, 2026).

EU regulations introducing *the* so-called *EU Battery Passport* reinforce the importance of reverse logistics as a carrier of information. Data on the production, composition, charging history, repairs and recycling of batteries become part of a digital ecosystem that accompanies the battery throughout its entire life cycle. For residual value, this means that vehicles with a complete, consistent battery history (data continuity from first registration, no 'gaps' in documentation) can be valued with a lower discount risk premium. Furthermore, vehicles with an incomplete history (lack of data on DC charging intensity, undocumented module repairs, lack of SoH reports) will be subject to greater value adjustments, even if they appear to be in good visual condition (Rizos, Urban, 2024).

Optimising remarketing for electric vehicles involves designing logistics and diagnostic processes in such a way as to minimise the time between a vehicle's return and its resale, whilst simultaneously enhancing the perceived quality and reliability of the offer. Return logistics is a key link here, as it determines both the speed at which a vehicle is prepared for sale and the quality of technical information, which influences the final price.

From the perspective of a retail or institutional buyer (e.g. SMEs purchasing used EVs for their fleet), professional diagnostics reduces the subjective risk of breakdown (which translates into a greater willingness to pay a higher price for a vehicle with a 'documented' battery), facilitates the comparison of offers (vehicles with similar mileage but different SoH will be priced differently, which promotes more effective market segmentation) and supports financing (financial institutions can base their risk models on hard data regarding battery condition rather than on conservative assumptions) (Fleet.com.pl, 2026; Kowalczuk, 2026; European Leasing Fund, 2026).

Leasing providers are particularly sensitive to residual value risk, as it is they who, in the classic operating lease model, bear the risk of the difference between the assumed and actual residual value of the vehicle. In the case of EVs, this risk is further exacerbated by uncertainty regarding battery longevity, the pace of technological progress and regulatory changes. Mature return logistics, integrated with diagnostic and analytical systems, is becoming a tool for reducing this uncertainty (Warelis, 2005; Polish Leasing Association, 2026).

Better predictability of residual value stems from the ability to base RV models on empirical data regarding battery degradation and vehicle performance over time, rather than on conservative assumptions. Fleet data (Arval, Geotab, P3, Aviloo) indicate that average battery degradation is approximately 1-2% of capacity, and after 8-10 years, many vehicles maintain an SoH of 80-85% (Michalak, 2026).

Reverse logistics, with a network of battery logistics centres, SoH testing standards, digital battery passports and integrated data systems, is becoming the infrastructure enabling such models. For lessors, this means the ability to transfer part of the residual value risk of the battery to specialised entities (manufacturer, BAAS operator), offer more flexible products (e.g. contracts with a guaranteed minimum SoH at the end of the term, battery replacement options during the contract period), as well as diversify revenue streams (a share of the value recovered from batteries in 'second-life' applications or raw material recycling) (Generational+, 2025; Wang, Huang, Chen, 2021).

5. Results

The operational approach to electric vehicle return logistics requires supplementation with an economic analysis in which residual value is treated as the result of a function of the revenues and costs of the entire asset management process. Unlike traditional models for internal combustion engine vehicles, where the main determinant is the market price of the vehicle, in the case of electric vehicles, the ability to actively manage value through the selection of an appropriate operating model is of key importance.

From an economic perspective, residual value can be expressed as the difference between the vehicle's selling price and the total cost of the return logistics process, encompassing both direct costs (transport, diagnostics, reconditioning) and indirect costs, in particular the cost of capital associated with the vehicle's turnover time and the cost of technological risk. This means that the decision on which operational model to choose should not be made solely on the basis of the potential selling price, but rather on the basis of maximising net value.

In the simplest direct remarketing model, operating costs remain relatively low; however, the lack of information on battery condition leads to a significant market discount. As a result, the net value obtained is often lower than in more advanced models, despite lower expenditure. The diagnostic-optimisation model generates higher initial costs, but reduces information asymmetry and enables a better-tailored sales strategy, which translates into higher transaction prices and a more stable residual value. The most advanced model for separating the battery from the vehicle offers the highest potential for value recovery, but its profitability is heavily dependent on the scale of operations, the availability of technological partnerships and market conditions, including the development of the secondary market for battery reuse.

Consequently, it can be concluded that, in the case of electric vehicles, reverse logistics ceases to be merely an operational function and becomes a key tool for managing the profitability of the leasing portfolio. Entities capable of integrating diagnostic, logistics and remarketing processes and reducing uncertainty regarding battery condition achieve a clear economic advantage. At the same time, a lack of investment in these areas leads to a systematic underestimation of residual value, which in the long term may significantly reduce the profitability of the entire leasing model.

To deepen the analysis of the profitability of electric vehicle return logistics processes, it is appropriate to adopt a formal residual value model based on discounted cash flows. In this approach, residual value is not treated as an exogenous parameter, but as the result of optimising a financial function dependent on the adopted operational model.

$$RV_{net} = P_{sale} - C_{log} - C_{tech} - C_{time} - C_{risk}$$

where:

RV_{net} denotes the net residual value,

P_{sale} the vehicle's selling price,

C_{log} logistics costs,

C_{tech} technical costs (diagnostics, reconditioning),

C_{time} the cost of capital associated with the asset's turnover time,

C_{risk} the cost of technological and market risk (Sierpińska, Jachna, 2022).

A key element of the model is the time component, which in practice is often underestimated, even though under leasing conditions it has a significant impact on profitability. This cost can be expressed as a function of the discount rate and the vehicle's turnover time:

$$C_{time} = P_{sale} \cdot (1 - e^{-r \cdot t})$$

where:

r denotes the cost of capital (e.g. the lessor's WACC),

t denotes the time required to utilise the vehicle (In more advanced models, such as battery regeneration or separation, the parameter$t$ increases significantly, which puts greater pressure on the efficiency of the other elements of the process) (Sierpińska, Jachna, 2022).

From a decision-making perspective, it is important to compare alternative operating models in terms of net present value (NPV). For a given logistics scenario, this value can be expressed as:

$$NPV = \sum_{i=0}^{n} \frac{CF_i}{(1+r)^i}$$

where:

CF_i denotes the cash flows generated by a given model (e.g. vehicle sales, battery sales, operating costs),

dr denotes the discount rate. In practice, this means that more advanced logistics models are economically viable only when the increase in revenue from a higher selling price or additional battery use exceeds the sum of additional costs and time costs (Sierpińska, Jachna, 2022).

A significant extension of the model is the inclusion of the value of the battery's alternative use (so-called 'second life'), which can be treated as a separate revenue stream:

$$P_{total} = P_{vehicle} + P_{battery}^{2nd\ life}$$

Including this component significantly alters the profitability structure, as it allows the residual value to be partially decoupled from the condition of the vehicle as a whole. At the same time, however, introduces additional risks linked to the uncertainty of the secondary battery market and the need to incur capital expenditure (Sierpińska, Jachna, 2022).

A comparative analysis indicates that the direct remarketing model maximises short-term liquidity and minimises operating costs, but at the same time generates the lowest expected value RV_{net} due to a high information discount. The diagnostic-optimisation model increases value by reducing information asymmetry, but its effectiveness depends on the relationship between diagnostic costs and the increase in the selling price. In contrast, the battery separation model is characterised by the highest value-generation potential, but its positive NPV occurs only under conditions of sufficient operational scale and access to a secondary market for battery reuse.

Consequently, the decision on which reverse logistics model to choose should be based on a marginal analysis, which compares the net value increase resulting from a more advanced process with its additional costs. This signifies a shift from a static approach, based on historical residual values, to a dynamic approach, in which this value is the result of deliberate optimisation of operational processes.

This approach leads to the fundamental conclusion that, in the context of electromobility, residual value ceases to be merely an input parameter for the leasing model and becomes its final outcome, dependent on the quality of asset management throughout the entire life cycle.

An important complement to the economic analysis are the legal conditions relating with the ownership of the traction battery and the allocation of risk among the parties involved. In the classic operating lease model, the lessor remains the owner of the vehicle and, upon termination of the contract, assumes full responsibility for its subsequent disposal. In the case of electric vehicles, however, this situation becomes more complicated, as the battery – being the key and most expensive component – may be subject to separate warranty terms or even constitute a separate object of ownership. In market practice, both models of full battery ownership by the lessor and hybrid solutions, in which responsibility for its technical condition remains partly with the manufacturer, are encountered. The lack of clear regulations and standards in this area increases legal and operational risks, particularly in the context of the possibility of battery separation, its further use (second life) and disposal obligations.

Consequently, the ownership structure and the scope of responsibility for batteries become key factors determining the efficiency of return logistics and the level of recoverable residual value.

Based on the analyses conducted, three models relating to the operation of return logistics for electric vehicles have been identified. Each presents a different approach to the management of vehicles and traction batteries at the end of their service life ( ), taking into account economic, organisational and systemic aspects. The presented models allow for an assessment of the relationship between the course of operational processes, the level of costs and risks, and the possibilities for increasing the efficiency of asset value recovery.

Option 1. Economic model of residual value

The first of the developed variants (Figure 1) relates to the economic dimension of electric vehicle return logistics. The model focuses on identifying factors influencing the final residual value of the vehicle and the traction battery at the end of their service life or financing period. It takes into account both potential sources of revenue related to the sale of the vehicle and the possibility of further use of the battery in a second-life model, as well as logistical and technical costs and risks arising from the asset's turnover time and technological uncertainty. In the presented approach, the residual value is the result of the relationship between the level of revenue generated and the scale of costs and risks involved in the vehicle's end-of-life management.

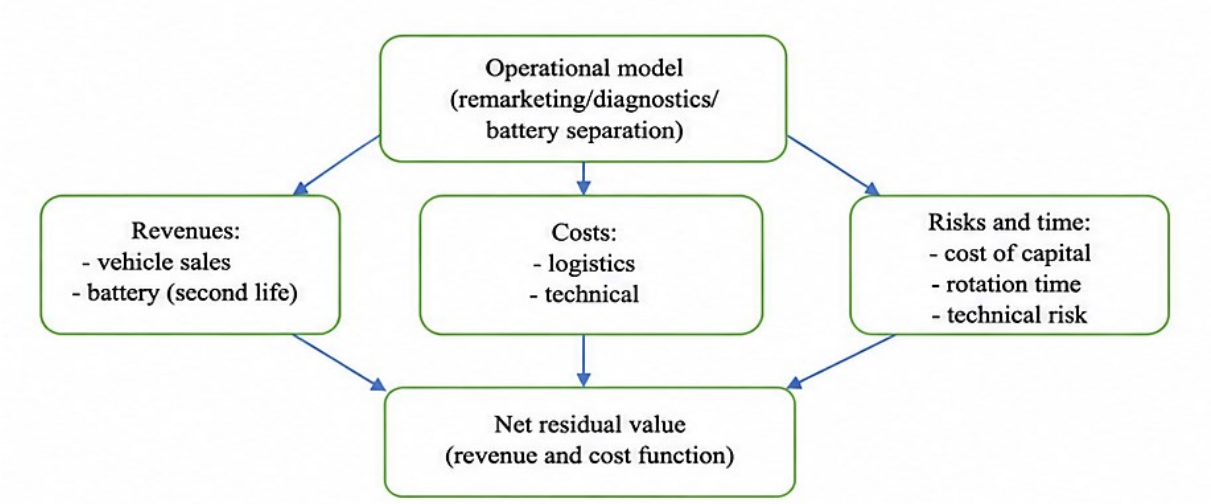

Figure 1 . Economic model of residual value.

Source: own work.

Option 2. Process-based model of return logistics

Option 2 (Figure 2) presents a process-based approach to organising the return logistics of electric vehicles. The model illustrates the successive stages of vehicle handling following its return, beginning with battery diagnostics, which determines the choice of the subsequent operational path. Depending on the technical condition, the vehicle may be sent for direct remarketing, undergo battery regeneration, or undergo a process of battery separation and be used in a second-life model. The individual pathways differ in terms of cost, operational complexity and potential recoverable value. The model indicates that properly matching the management process to the actual technical condition of the components can significantly influence the economic efficiency of the entire return logistics process.

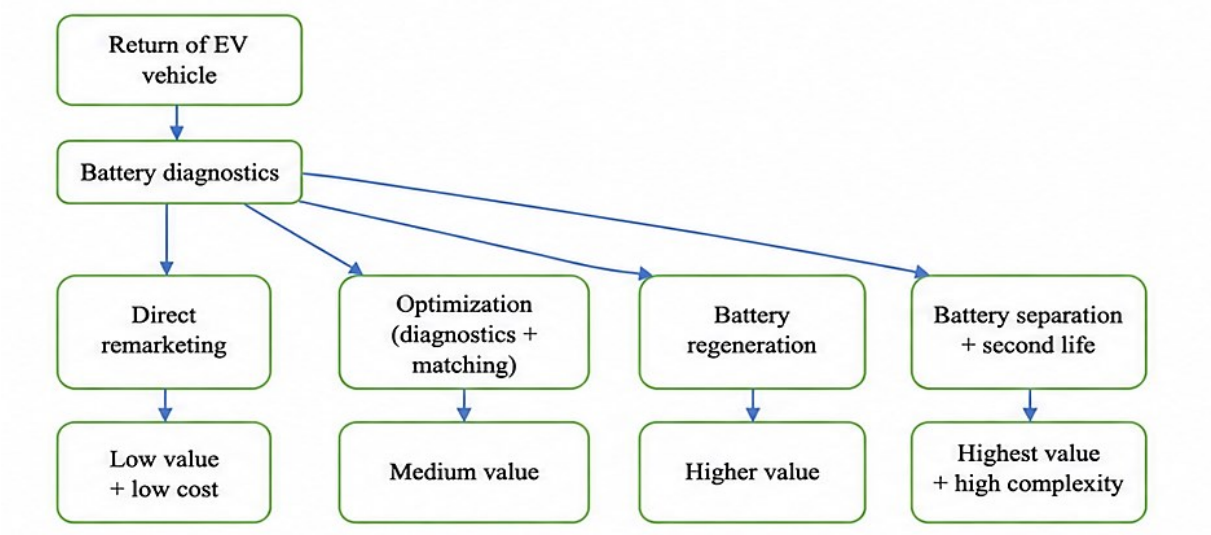

Figure 2. Reverse logistics process model.

Source: own work.

The third variant (Figure 3) presents a systemic approach to reverse logistics in the electromobility sector. The model assumes that the efficiency of processes related to the recovery of value from electric vehicles depends both on operational factors within the organisation and on market and regulatory conditions. Of particular importance are the development of the secondary battery market, the volatility of electric vehicle prices, access to diagnostic technologies, the level of specialisation of the entities involved in the process, and the company's ability to build operational partnerships.

The systemic model assumes interdependence between the individual elements of the reverse logistics process, including battery diagnostics, the organisation of logistics processes, sales strategy, and activities related to remarketing and the use of batteries in a second-life model. The efficiency of each of these areas directly influences the vehicle's final residual value and the potential for optimising operating costs. At the same time, the model indicates that a lack of integration between the various participants in the process can lead to longer asset turnover times, increased costs and heightened technological risk.

From a systemic perspective, reverse logistics is not a single operational process, but an integrated mechanism for managing the flow of vehicles, components and information. This necessitates the coordination of activities between lessors, vehicle manufacturers, logistics operators, battery reconditioning entities and participants in the secondary market. In practice, the efficiency of the entire system depends on the degree of process standardisation, access to technical data, and the ability to quickly assess the condition of the traction battery. The model also highlights the importance of legal regulations and the development of energy storage technologies, which in the coming years may significantly influence the profitability of second-life processes and the level of residual value achieved.

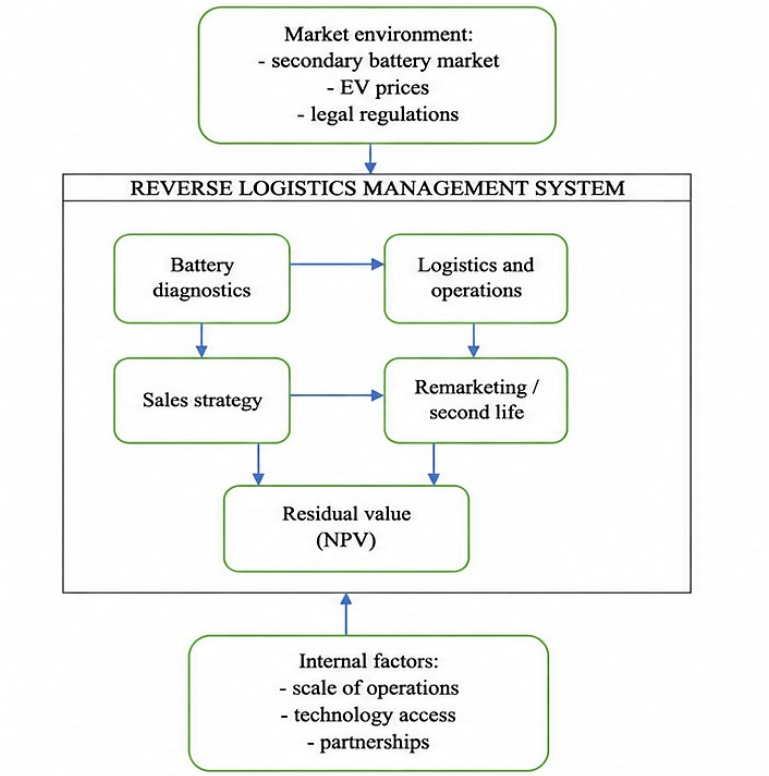

Figure 3. System model of reverse logistics.
Source: own work.

6. Discussion

The conducted analysis indicates that the residual value of electric vehicles under operating leases is determined by a significantly broader range of factors than in the case of vehicles equipped with internal combustion engines. The literature reviewed and the models presented in this article confirm that battery degradation processes, the organisation of reverse logistics and the availability of information concerning battery condition jointly influence the final value of the vehicle at the end of the leasing period.

Particular importance should be attributed to the State of Health (SoH) parameter, which increasingly becomes one of the main determinants of residual value in the secondary market. The results of the analysis suggest that battery condition affects not only the technical performance of the vehicle, including driving range, but also the perception of risk among potential buyers. Vehicles with documented battery condition and a transparent service history are generally associated with lower uncertainty, which may positively influence their market valuation. At the same time, the lack of uniform standards for measuring and reporting SoH remains one of the major barriers limiting the development of reliable residual value assessment methods.

The analysis also demonstrates that reverse logistics may become an important tool for reducing residual value risk. Properly organised battery diagnostics, standardised testing procedures, the use of battery passports and effective remarketing processes contribute to reducing information asymmetry between market participants. This is particularly important from the perspective of leasing companies, which bear the residual value risk throughout the contract period and therefore require reliable methods of assessing the technical condition of returned vehicles.

The three reverse logistics models presented in this study illustrate different approaches to value recovery. The economic model focuses on the relationship between revenues, costs and risks associated with vehicle disposal. The process-based model emphasises the role of diagnostics and the selection of the most appropriate pathway for further utilisation of the vehicle and battery. In turn, the systemic model highlights the importance of cooperation between lessors, vehicle manufacturers, logistics operators, recyclers and entities involved in second-life applications. The comparison of these models indicates that increasing organisational complexity may also increase the potential for value recovery, provided that the necessary technical infrastructure and operational competencies are available.

The conducted research is subject to several limitations. First, the analysis is based primarily on literature studies and available market reports, without access to proprietary operational data from leasing companies or vehicle manufacturers. Secondly, the dynamic development of battery technologies and the limited availability of long-term market observations make it difficult to formulate universal conclusions regarding future residual value trends. Furthermore, differences in battery chemistry, vehicle segments and operating conditions affect the comparability of the results presented in the literature.

The findings presented in this article indicate several directions for further research. In particular, there is a need to develop quantitative models linking battery SoH with residual value under different operating scenarios. Further studies should also examine the economic effectiveness of second-life battery applications, the development of Shared Reverse Logistics solutions and the impact of the EU Battery Passport on residual value management in the leasing sector. The growing importance of electric vehicles suggests that these issues will become increasingly relevant for both researchers and market practitioners.

7. Conclusions

The research conducted has shown that reverse logistics processes play a key role in determining the residual value of electric vehicles under operating leases. Of particular importance are the quality of traction battery diagnostics, the organisation of remarketing processes, and the possibility of utilising batteries in regeneration and second-life models.

As the EV market grows in importance, reverse logistics ceases to fulfil a purely operational function, becoming a strategic element of residual value risk management.

The proposed conceptual models of return logistics for electric vehicles present different approaches to managing the residual value of the vehicle and the traction battery. The economic model highlights the relationships between revenue, operating costs, and the technical and capital risks affecting the final value of the asset. The process model illustrates possible pathways for the utilisation of the vehicle and battery after the end of the lease agreement – ranging from direct remarketing to regeneration and second-life applications. The system model, in turn, emphasises the importance of integrating diagnostics, logistics, sales strategies and market factors within a comprehensive return logistics management system.

In practice, companies involved in operating leases and vehicle fleet management are increasingly implementing specialised procedures for handling the return of electric vehicles. This process includes a technical assessment of the traction battery, an analysis of the vehicle's operational history, verification of SoH parameters, and the classification of the vehicle for the appropriate disposal pathway. Depending on its technical condition, the vehicle may be directed for direct remarketing, a regeneration process, or component recovery, including the use of the battery in second-life applications.

In market practice, there is also a growing trend towards collaboration between lessors, logistics operators, technical service providers and entities specialising in battery diagnostics. The aim of these measures is to mitigate residual value risk by shortening vehicle turnover times, improving the quality of valuations and increasing the transparency of technical data. Telematics tools and digital battery passports are also becoming increasingly important, enabling the monitoring of operational parameters throughout the vehicle's entire service life.

For large fleet operators, return logistics is becoming an integral part of asset management strategy, rather than merely an operational process carried out upon the expiry of a lease agreement. This allows for more accurate forecasting of the residual value of electric vehicles and reduces the financial risk associated with the dynamic growth of the electromobility market.

The SoH indicator is becoming a central parameter in asset management for leasing and fleet companies, as it determines the residual value of vehicles, service risk and the possibility of further use of traction batteries in second-life applications. The lack of uniform standards for measuring SoH leads to information asymmetry and hinders the development of stable financing models for electric vehicles. Research into SoH estimation methods highlights the need for repeatable, auditable procedures based on data from BMS systems, supplemented by workshop tests.

Companies should implement standardised SoH testing protocols, covering capacity and resistance measurements as well as analysis of the battery's operational history. The SoH parameter may in future become a contractual element in leasing agreements and part of periodic reporting for fleet customers. The integration of telematics with predictive analytics

enables real-time monitoring of battery degradation, which aligns with the trend of treating batteries as data management assets.

At the same time, the importance of specialised EV battery return logistics is growing. Forecasts indicate a dynamic increase in the number of batteries being taken out of service, which requires the development of infrastructure to enable their classification, diagnostics, dismantling and redirection for recycling or stationary applications. Shared reverse logistics models can enhance economic and environmental efficiency, particularly when vehicle manufacturers, fleet operators and recycling companies collaborate.

Furthermore, leasing companies should develop their own or shared EV reverse logistics centres, serving as diagnostic and distribution hubs. The implementation of battery tracking systems, the standardisation of dismantling processes, and integration with recycling partners and entities involved in the use of batteries in second-life applications are of key importance. Cooperation with vehicle manufacturers and recycling companies is essential to ensure data consistency, process safety and maximise material recovery. OEMs possess knowledge of battery architecture and BMS algorithms, which enables more accurate modelling of degradation processes and more effective resolution of warranty issues.

In summary, electric vehicle battery management requires a systematic approach, encompassing the standardisation of SoH parameters, the professionalisation of return logistics, the development of cooperation with manufacturers and recyclers, and user education. Companies that build an integrated ecosystem for battery management and return logistics can gain a cost and organisational advantage in the growing electromobility market.

Despite the growing body of literature on battery degradation and reverse logistics, significant challenges remain regarding the standardisation of State of Health assessment and the integration of battery-related information into residual value management. The results presented in this article indicate that effective reverse logistics systems, supported by reliable diagnostics and transparent information flows, may become an important factor reducing residual value risk in the electric vehicle leasing market.

Future research should focus on the development of quantitative models linking battery State of Health with residual value under different operating conditions and market scenarios. Further studies may also investigate the long-term economic effectiveness of Shared Reverse Logistics solutions and the impact of emerging regulations, including the EU Battery Passport, on leasing risk management and vehicle valuation processes.

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PSYCHOLOGICAL ASPECTS OF STUDENTS' QUALITY OF LIFE IN THE CONTEXT OF THEIR CAREER PREFERENCES

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Purpose: The aim of this article is to analyse research on the relationship between students' quality of life and their career preferences. The author focuses on how the alignment between personal predispositions and career choice affects students' mental well-being, stress levels and overall life satisfaction.
Design/methodology/approach: The study is based on a structured literature review conducted using databases such as Scopus, Web of Science, and Google Scholar. The analysis included peer-reviewed publications from 2015-2025.
Findings: The results indicate a shift in students' career thinking from economically driven decisions towards value-based and well-being-oriented choices. Work-life balance, autonomy, and meaningful work are key predictors of quality of life.
Research limitations/implications: The study is based on a literature review, which limits direct empirical verification.
Practical implications: The shift in students' priorities has specific implications for three groups: higher education institutions, which must integrate professional psychological support with career guidance and develop in students such competencies as emotional intelligence and mental resilience; career counsellors, whose role should evolve from that of an expert to that of a coach who supports students in shaping their professional lives in line with their values; and employers, who must offer more than just a salary to attract talented people.
Social implications: The article highlights profound social implications, as changing students' priorities redefine the concept of success, shifting the emphasis from earnings to mental well-being and work-life balance. This forces a transformation of the labour market towards flexibility and meaningful work, whilst elevating the importance of mental health in public debate.
Originality/value: The value of this article lies in its synthesis of recent Polish and international research documenting a fundamental paradigm shift in career thinking. The article comprehensively analyses the psychological underpinnings of this change and presents its practical implications for education and the labour market.
Keywords: quality of life, career preferences, students, mental health, career guidance.
Category of the paper: Literature review.

1. Introduction

A key stage in human development is the period of higher education, which is characterised by intensive social, intellectual and personal development. It is also a time to make fundamental decisions about a future career path. The period of study provides a solid professional foundation by equipping students with specialist knowledge essential to many professions. It is at university that young people develop the ability to think critically, analyse complex problems and seek creative solutions. The time spent on projects and in teamwork is an invaluable lesson in time management and collaboration – skills highly valued in today's job market. Through internship programmes and careers services, universities also serve as the first bridge between academia and the professional world, offering opportunities to gain valuable experience.

Equally important is the intensive personal development that takes place during this period. For many students, going to university means moving out of the family home for the first time, and consequently, a real lesson in independence. The need to manage one's own budget, organise one's day and make fully independent decisions accelerates the process of maturing. A university is also a space where different ideas, cultures and worldviews clash. Taking part in discussions, meeting people from different backgrounds, and engaging with new perspectives broaden horizons and help shape one's own identity. Involvement in academic societies or student organisations often allows students to discover passions that last a lifetime.

Nor should we forget the immense social capital that is built up during this time. Relationships formed at university, based on shared experiences of challenges, intensive study, and everyday concerns, often develop into lifelong friendships. Relationships with fellow students and lecturers, in turn, form an invaluable professional network that can pay dividends in the future. It is precisely in this diverse environment that a young person learns to function in society, communicate and collaborate with others.

Hence, the period of study is a kind of investment that shapes not only a specialist in a given field but, above all, a conscious, mature and well-rounded individual.

The quality of students' lives is a subject of growing interest in health psychology, educational psychology and occupational psychology alike. It cannot be denied that the period of study is a time of intense psychosocial and decision-making challenges for young people, which affect their quality of life, mental health and the shaping of their future career preferences, including professional identity, aspirations and adaptability to a dynamically changing labour market (Super, 1990; Holland, 1997; Lent, Brown, Hackett, 1994).

Students' quality of life, understood as a subjective assessment of their own life situation in physical, mental, social and environmental terms, is inextricably linked to the process of shaping their professional identity.

Choosing a career path is one of the key developmental tasks in early adulthood, and the decisions made at this time have a fundamental impact on an individual's subjective quality of life. Contemporary research, conducted both in Poland and internationally, increasingly focuses on analysing this relationship, emphasising that students' career preferences extend far beyond the traditional pursuit of financial stability. These include complex psychosocial factors, such as the need for meaning, work-life balance, and the alignment of work with personal values, which become key predictors of overall well-being.

The aim of this article is to analyse the relationship between students' quality of life and their career preferences in the context of current socio-economic changes.

The main research problem is formulated as follows: *What psychological factors determine the relationship between students' quality of life and their career preferences?*

The following research hypotheses are proposed:

H1: Alignment between personal values and career choice positively influences students' quality of life.

H2: High levels of academic stress negatively affect quality of life and modify career preferences.

H3: A sense of meaning in life serves as a protective factor for students' mental well-being.

The findings contribute to the development of contemporary models of career guidance and educational policy.

2. The concept of quality of life and career preferences in theoretical terms – literature review

Quality of life is one of the key concepts in contemporary health psychology, positive psychology and interdisciplinary research on human well-being. Despite its long-standing presence in the scientific literature, the concept remains conceptually ambiguous and multidimensional.

Classical approaches have emphasised that quality of life cannot be reduced solely to material or physical functioning but encompasses a subjective assessment of one's own life situation, embedded in cultural, axiological, and personal contexts (Sirgy, 2021). Quality of life is a construct that integrates physical, psychological, social, and environmental components, with the psychological component increasingly recognised as the most significant dimension (Haraldstad et al., 2019). Thus, quality of life encompasses both an individual's subjective experiences (e.g. emotional well-being, life satisfaction) and objective living conditions (e.g. health, social functioning, access to resources).

According to the World Health Organisation's definition, quality of life is "an individual's perception of their life situation in the context of the culture and value systems in which they live, and in relation to their goals, expectations and concerns" (WHOQOL Group, 1995). This definition laid the foundations for modern, psychologically oriented research into quality of life, shifting the focus from objective indicators of well-being to the individual's subjective experience. Generally speaking, this definition emphasises three key elements. Firstly, subjectivity, quality of life is inherently subjective and based on individual assessment. What constitutes a high quality of life for one person may be of no significance to another. Secondly, multidimensionality encompasses various aspects of life, such as physical health, mental well-being, social relationships, and the environment. Thirdly, contextuality, which means that the assessment of quality of life is embedded in a specific cultural context and the individual's value system.

At this point, it is important to distinguish quality of life from related concepts, such as standard of living, which refers mainly to objective, material living conditions (income, housing conditions, access to services), and well-being, which often focuses on the psychological aspect, encompassing life satisfaction and affective balance (the predominance of positive emotions over negative ones). Quality of life is an overarching concept that integrates these and other dimensions.

The psychological dimension of quality of life encompasses a broad spectrum of intrapsychic processes, including emotional well-being, cognitive functioning, self-esteem, a sense of meaning in life, emotional regulation, and the subjective perception of one's own worth and agency (Jones, Drummond, 2021).

Contemporary research on quality of life increasingly draws on the dual concept of psychological well-being, which distinguishes between the hedonic and eudaimonic dimensions of functioning (Ryan, Deci, 2001). Hedonic well-being refers to a subjective sense of happiness, life satisfaction and the balance of positive and negative emotions, whereas eudaimonic well-being focuses on self-actualisation, a sense of meaning and the alignment of one's life with one's values. Empirical research confirms that both dimensions of well-being are significant predictors of quality of life, with the eudaimonic component showing stronger links to long-term assessments of quality of life (Gautam et al., 2024). This implies that momentary emotional satisfaction is less significant than a lasting sense of meaning and purpose in life.

Taking the above into account, an analysis of quality of life would be incomplete without considering the professional sphere, which for most adults, constitutes one of the central domains of life, absorbing a significant portion of their time and energy and serving as a key source of income, identity and social relationships. The relationship between quality of life and professional preferences is complex and bidirectional, and understanding it requires integrating theories from occupational psychology, career guidance, and well-being research.

In response to the growing importance of the professional sphere, the concept of quality of life at work or work-related quality of life has been identified in the literature. It is defined as a subdomain of overall quality of life, which refers to an employee's perception and evaluation of the full spectrum of experiences related to the work environment (Van Laar, Edwards, Easton, 2007). Quality of life at work is a multidimensional construct, encompassing aspects such as:

- Job satisfaction – the overall affective attitude towards one's work.
- Well-being at work – a sense of psychological comfort, absence of excessive stress and burnout.
- Work-life balance – the perceived ability to harmoniously combine professional demands with the responsibilities and pleasures of personal life.
- Control and autonomy at work – the extent to which an employee has influence over their tasks, pace and working methods.
- Career development and job security – opportunities for promotion, learning new skills and a sense of job stability.
- Working conditions – the physical and organisational aspects of the working environment.

Career preferences refer to individual career choices and priorities, which are shaped by personal values, abilities and external economic conditions. Based on their experiences and aspirations, each person develops a set of preferences that influence decisions regarding their career path.

Career preferences are an individual's relatively stable tendencies to choose specific types of professional activities, work environments, and professional roles. They encompass interests, values, beliefs and subjective assessments of one's own abilities and aptitudes, which guide decisions regarding career choice and career development. In the psychological literature, career preferences are regarded as an important element of personality structure, influencing how a person functions in both work and non-work life (Bajcar et al., 2006).

One of the most frequently cited concepts explaining the mechanism behind the formation of career preferences is John L. Holland's theory. The author posited that career choices are an expression of personality, and that people seek work environments that allow them to realise their dominant traits, interests and values. Holland identified six types of career preferences (realistic, investigative, artistic, social, enterprising and conventional), pointing out that a match between a person's type and their work environment promotes job satisfaction and career stability. A lack of such compatibility, however, can lead to frustration, reduced commitment and frequent job changes (Holland, 1992).

Career preferences also play a significant role in an individual's professional development, according to Donald E. Super. In his concept, career development is a lifelong process, and career preferences change with experience, successive life stages, and the formation of

one's self-image. Super emphasised that work fulfils not only an economic function, but also psychological and social ones – it enables self-actualisation and the development of a sense of meaning in one's own life (Super, 1990). For this reason, an accurate understanding of one's own career preferences facilitates the harmonious integration of professional and personal roles.

Career preferences are crucial to quality of life, as work not only provides financial stability but also enables the fulfilment of individual goals and aspirations. A career that aligns with personal preferences leads to increased life satisfaction and better mental health, as work fulfils not only material needs but also emotional and social ones (Ramawickrama, Opatha, Pushpakumari, 2017). Aligning work with career preferences increases motivation and commitment, which translates into lower work-related stress and has a positive impact on personal life and relationships with others. In this way, career preferences become an important element of work-life balance (Van der Doef, Maes, 1999).

Research on the quality of working life indicates that people working in line with their preferences are more likely to experience a sense of meaning in their work, autonomy and opportunities for development, which translates into overall life satisfaction. Conversely, long-term employment in a profession that does not align with one's preferences can reduce quality of life, increase stress levels and lead to burnout (Warr et al., 1979). Career preferences, therefore, serve a protective function, fostering a balance between work and personal life.

In summary, career preferences are a key factor determining educational and career choices, as well as an individual's performance at work. Taking them into account in the career planning process promotes not only professional effectiveness but also a high quality of life, understood as a subjective sense of well-being and satisfaction with one's life roles.

3. Students' career preferences and quality of life – a review of research

Students' career preferences currently constitute one of the key areas of research in the social sciences, as they reflect not only current labour market conditions but also profound changes in how younger generations perceive quality of life. It is becoming increasingly clear that students' career choices are not solely the result of rational economic calculation but the outcome of a complex interaction among structural conditions, cultural expectations, and the individual pursuit of psychological well-being, meaning, and autonomy (European Commission, 2023). In this context, work is seen as an integral part of quality of life, rather than its overriding determinant.

Research conducted in Poland indicates that financial security remains a key factor in students' positive assessment of their quality of life. The results of the EUROSTUDENT VIII survey show that students who report stable sources of income and prefer predictable forms of employment exhibit higher life satisfaction and lower levels of financial stress

(EUROSTUDENT, 2024). A lack of financial stability hinders future planning and reduces the sense of control over one's own life, which translates into more conservative career preferences. Similar correlations are evident in international studies, where post-COVID-19 employment uncertainty has been unequivocally linked to a decline in students' mental well-being and a tendency to choose safe, albeit less aspirational, career paths (Pshembayeva, Pfeyfer, Uaikhanova, Bubenchikova, 2022).

At the same time, the literature on the subject points to the ambivalent role of taking up work whilst studying. On the one hand, moderate employment helps build career capital and strengthens a sense of independence and agency. Research conducted in Poland shows that students who combine study with part-time work report higher levels of autonomy and a more positive assessment of their quality of life (Kunasz, 2022). On the other hand, an excessive workload leads to role conflict, chronic fatigue and reduced life satisfaction. This phenomenon has also been widely documented in international research, which highlights the negative impact of excessive work on mental well-being and a sense of purpose (Pham, Lam, Bui, 2024).

A common theme in both Polish and international research is the growing importance of work-life balance as a key criterion in students' career preferences. Polish studies have shown that flexible working hours, the possibility of remote work, and respect for free time are perceived as fundamental conditions for a high quality of life, often more important than pay levels (Skórska, 2022). Similar conclusions are drawn in international studies, where work that enables a balanced life is significantly correlated with higher levels of mental well-being and a lower risk of burnout (Hsu, Ye, Ling, 2022).

The axiological and existential dimensions of work are also playing an increasingly significant role in shaping students' career preferences. Polish research on the so-called Protean attitude indicates that students and young adults increasingly define their careers in terms of autonomy, personal development, and the integration of work with other spheres of life, thereby contributing to a higher subjective quality of life (Blachnicka, 2022). Similar conclusions emerge from European research, which has shown that students with strongly internalised prosocial and moral values are more likely to link quality of life to a sense of meaning and the social utility of their future work (Kuusisto, de Groot, de Ruyter, Schutte, Rissanen, 2023).

Systematic reviews of European research also emphasise the particular importance of meaning in life and work. They indicate that a sense of meaning serves a protective function for students' mental health, reducing anxiety and depression and enhancing life satisfaction (Ortega‐Gómez, García‐Barrena, Martínez-Álvarez, Baca-García, 2025). According to recent reports, approximately 30-40% of students experience symptoms of anxiety and depression, while a significant proportion report high levels of stress and emotional exhaustion, which has a direct impact on both their quality of life and career decision-making processes (HMS 2024-2025). It has also been noted that self-efficacy in making career decisions is significantly associated with self-esteem, professional identity, peer support, expectations regarding outcomes, and uncertainty about future career paths (Wang D., Li, Wang G., 2024). Vashisht

and colleagues, however, confirmed that students with emotional control and certain personality traits (the Big Five) were better able to improve their career adaptation, based on a systematic review (Vashisht et al., 2021). It was also confirmed that emotional intelligence, measured by empathy, the use of emotions, coping with relationships and self-control factors, is positively associated with self-efficacy in making career decisions, and that the use of emotions and self-control factors was inversely associated with career exploration and engagement (Brown, George-Curran, Smith, 2003).

A Polish report compiled by a SWPS team on behalf of the Ministry of Science and Higher Education noted that the prevalence of depression, anxiety and burnout in the academic environment significantly reduces quality of life and hinders rational career planning, emphasising the need for systemic mental health support at universities (Report: Analysis of research on mental health and quality of life in the academic environment, 2024).

A lack of meaning in work, however, is associated with a negative assessment of one's future career and a lower quality of life, even when economic criteria are met. In this context, career preferences should be interpreted not only as a response to market conditions but also as a means of fulfilling the fundamental psychological and existential needs of young adults (Green, Lee, Zou, Zhou, 2024).

An integrated analysis of Polish and international research indicates that students' career preferences are increasingly linked to a holistic understanding of quality of life. In this context, work occupies an important but not dominant role, supporting well-being, autonomy, and a sense of purpose in life. This trend points to a lasting shift in the paradigm of career thinking, observed in both Poland and other countries.

Research conducted at Polish academic institutions indicates that students' career preferences and subjective quality of life are strongly influenced by structural, psychosocial, and cultural factors, particularly their field of study, material status, educational experiences, and perceived employment prospects. Analyses by Trzcionka and colleagues, conducted on students at three Polish universities, revealed significant differences in mental and social quality of life depending on the type of degree programme studied. Medical students reported a lower quality of mental life, but at the same time, more stable career preferences, which the authors attribute to a clearly defined career path (Trzcionka et al., 2022).

In turn, Skórska's research showed that students combining study with work are more likely to prefer flexible forms of employment in the future, whilst also rating their current quality of life lower in terms of leisure time and mental well-being (Skórska, 2022). This tendency is consistent across both Polish and international studies; however, research suggests that the importance attributed to work-life balance is particularly pronounced among students in developed European countries compared to other regions, where economic factors may still play a more dominant role.

In research on the career aspirations of Generation Z, Anisiewicz found that students are primarily guided by post-materialistic values, such as the meaning of work and work-life balance, which positively correlates with their reported overall quality of life, regardless of projected earnings (Anisiewicz, 2023).

In contrast, research by Paszkowska-Rogacz further demonstrated that students' life orientation and level of self-regulation differentiate their career adaptability; individuals with a higher promotional orientation not only chose dynamic career paths more frequently but also reported higher life satisfaction (Paszkowska-Rogacz, 2024). These findings are complemented by Czeranowska's analyses, which indicate that students' subjective understanding of professional success significantly influences their career preferences and assessments of quality of life, with students emphasising objective success (income, prestige) more frequently reporting stress and lower psychological well-being (Czeranowska, 2022).

In turn, international research confirms that these relationships are universal, though they are modulated by cultural and institutional contexts. Lipshits-Braziler, Arieli and Daniel, analysing a sample of young adults, including students, demonstrated that alignment between personal values and career preferences significantly predisposes individuals to higher levels of life satisfaction, whilst a lack of such alignment is associated with reduced quality of life as early as the undergraduate stage (Lipshits-Braziler, Arieli, Daniel, 2024).

From the perspective of job quality, Green and co-authors have demonstrated that students attach the greatest importance to job quality understood as autonomy and meaningfulness, and that these factors have a greater impact on well-being than financial expectations, which has a direct bearing on their career preferences (Green, Lee, Zou, Zhou, 2024).

Research by Pham and colleagues on Vietnamese students showed that exploration of the professional environment and social support significantly influence career choices, whilst indirectly enhancing perceived quality of life through an increased sense of agency (Pham, Lam, Bui, 2024).

From a systematic perspective, Abdullah, Zakaria and Zahoor indicated that the quality of professional life, which is already shaped during the study phase, is the result of the interaction between the university's organisational conditions, the academic workload and students' individual resources, which differentiates their attitudes towards their future careers (Abdullah, Zakaria, Zahoor, 2021).

Age and developmental stage also proved to be significant differentiating factors, as confirmed by the analyses of Alabbad, Cochrane and Mitchell, which show that younger students value the health and professional components of quality of life differently from older students, which translates into differing preferences regarding career stability and flexibility (Alabbad, Cochrane, Mitchell, 2025).

4. Methods

The present study is based on a structured review of the subject literature, the aim of which was to identify key relationships between students' quality of life and their career preferences.

The analysis was conducted on the basis of scientific publications available in international databases such as Scopus, Web of Science, and Google Scholar. The search process employed a set of keywords including, among others, "quality of life", "students", "career preferences", "mental health", and "work-life balance", which enabled the identification of the most relevant sources. Publications meeting specific criteria were included in the analysis, in particular peer-reviewed articles published between 2015 and 2025, focusing on student populations and issues related to quality of life and career choices. Based on the adopted criteria, the research material was selected, comprising several dozen high-quality scientific publications.

Exclusion criteria included non-peer-reviewed publications, studies not focusing on student populations, articles not addressing quality of life or career preferences, and papers with insufficient methodological rigor.

To develop the results, qualitative content analysis and a synthetic approach were applied, which made it possible to identify the main research trends, relationships between variables, and the most important conclusions drawn from the analyzed studies.

5. Results

The conducted literature analysis made it possible to identify significant changes in the way students perceive professional careers, as well as to determine the key factors influencing their quality of life. In particular, a clear transformation in attitudes toward work can be observed, with work no longer regarded as the primary goal in life, but rather as one of many elements contributing to overall quality of life.

The findings indicate that, within the contemporary academic environment, psychological factors are gaining increasing importance, directly influencing career decision-making processes. High levels of stress, anxiety, and symptoms of burnout significantly reduce students' subjective quality of life, while simultaneously limiting their capacity for rational career planning. Conversely, factors such as a sense of meaning in life, a sense of agency, and emotional stability serve a protective function and foster more conscious and satisfying career choices.

The analysis also reveals a significant shift in the hierarchy of values determining students' career preferences. Although financial security remains an important element, it no longer constitutes the dominant decision-making factor. Increasing importance is attributed to work–

life balance, flexibility of employment forms, opportunities for remote work, as well as autonomy and the possibility of self-fulfilment at work. Particularly notable is the need to engage in work that aligns with one's values and provides a sense of meaning and purpose.

Furthermore, the results indicate that students' career preferences are shaped in close relation to their educational experiences, financial situation, and social context. These factors differentiate both the level of quality of life and expectations regarding future careers. At the same time, it is observed that the contemporary generation of students strives toward a more balanced model of functioning, in which professional work constitutes an important, yet not dominant, component of life.

In conclusion, the obtained results confirm the existence of a clear tendency toward redefining the role of work in young people's lives, as well as the growing importance of psychological and axiological factors in shaping career preferences and quality of life.

6. Discussion

The analysis of the relevant literature allows us to formulate a thesis about a fundamental reconfiguration of the priorities guiding students as they shape their career preferences. The observed process goes beyond a mere adjustment of expectations, as it bears witness to a profound paradigm shift – a transition from a model in which a career was the central axis of life and the main determinant of status, to a model where work is perceived as one of many, albeit significant, components of a holistically understood quality of life. In light of the data collected, young people's career choices appear less like a pursuit of maximising economic gains and more like a conscious strategy for building a life that is consistent with personal values, ensures psychological well-being, and enables self-fulfilment.

A key insight emerging from my analysis is the growing significance of the eudaimonic dimension of well-being. Classical theories, such as John Holland's concept of person-environment fit, remain relevant but require significant supplementation. The alignment of personality traits with the nature of work remains an important predictor of satisfaction; however, for contemporary students, the alignment of work with their value system, sense of meaning and life goals is becoming equally crucial. In this context, Donald Super's concept takes on new significance – students strive for the harmonious integration of their professional role with other life roles (family, social, personal), rather than subordinating their entire lives to the demands of their career. This shift is a response to broader socio-cultural trends, such as growing awareness of the importance of mental health, or the instability and unpredictability of the global labour market. The catalysts for these processes are undoubtedly advancing globalisation and the technological revolution, which operate in two ways. On the one hand, digital technologies and the global flow of information have removed the barrier of the physical

office, making remote and hybrid work not only possible but even desirable. This offers students a real prospect of achieving the much-valued flexibility and autonomy. On the other hand, these same forces generate a sense of uncertainty, in the face of which young people seek ‘anchors’ not in external guarantees of job stability, but in an internal sense of meaning and control over their own lives.

The identified trends carry far-reaching practical implications for, amongst others, higher education institutions, career counsellors and career psychologists, as well as employers and organisational leaders.

In addition to imparting specialist knowledge, universities face the urgent task of equipping students with the psychological resources necessary to navigate the complex labour market. The mere existence of careers offices is no longer sufficient. A systematic integration of career guidance with professional psychological support is essential. Furthermore, curricula should be enriched with modules that develop key future competencies, such as emotional intelligence, critical thinking, mental resilience and adaptability.

The role of the career counsellor must be redefined – from an expert pointing out optimal paths to a partner and coach who supports the student in designing their own professional life. This requires a shift away from diagnostic tools focused solely on aptitudes and interests towards methods that allow for deep reflection on values, needs and one’s personal definition of success. Guidance should become a process that strengthens self-efficacy and teaches flexibility in career planning.

To attract and retain the best talent, organisations must review their value proposition for employees. Salary and material benefits, whilst remaining the foundation, are becoming ‘hygiene factors’ – their absence is demotivating, but their mere presence is no longer sufficient to build engagement. It should be noted that this is no longer merely a proposal, but an observable market reality. The most innovative companies are already modifying their recruitment strategies. Communication in job advertisements is shifting from the language of requirements to the language of an invitation to jointly build a valuable future. Increasing emphasis is being placed on organisational culture, the company’s mission and opportunities for development. Key values in the labour market are becoming, amongst others: autonomy (influence over how, where and when work is performed), flexibility (a genuine, rather than superficial, ability to balance life roles), an organisational culture based on trust and psychological safety, and, most importantly, a sense of purpose (clear communication of the company’s mission and demonstrating the impact of an individual’s work on the fulfilment of that mission).

The findings confirm a fundamental transformation in students’ career orientation. Traditional models focusing primarily on economic factors are no longer sufficient.

Holland’s theory remains relevant but requires extension to include values and meaning. Similarly, Super’s concept of life roles gains new importance, as students strive for integration rather than dominance of professional life.

The growing importance of eudaimonic well-being reflects a shift toward more holistic life strategies. Students seek not only employment but also personal fulfilment, autonomy, and psychological comfort.

These results are consistent with contemporary international research highlighting the role of meaning, identity, and mental health in career development.

7. Conclusions

This article presents a synthetic analysis of the psychological aspects of students' quality of life, highlighting a fundamental shift in their approach to their professional careers. The principal thesis is the transition from a model in which a career was the central goal to the perception of work as one of many elements of a holistically understood quality of life. In this study, quality of life is defined as a subjective, multidimensional assessment of one's own situation, encompassing psychological well-being, social relationships and alignment with personal values. In turn, career preferences, based on the theories of Holland and Super, are presented as an expression of personality and a pursuit of self-actualisation.

The review of Polish and international research demonstrates that whilst economic security remains significant, it is no longer the main criterion for choosing a career path. New priorities are coming to the fore, such as work-life balance, the possibility of remote work, and the search for work that provides a sense of meaning and aligns with personal values. Autonomy and the opportunity for personal development are becoming equally important. The article also strongly emphasises the importance of mental health, pointing out that high levels of stress and anxiety among students negatively affect their well-being and ability to plan for the future, and that a sense of purpose serves a protective function in this context.

This shift in young people's priorities has specific practical implications. Universities face the task of integrating psychological support with career guidance. The role of counsellors should evolve towards coaching that helps shape lives in line with individual values. Employers, in turn, must offer more than just a salary to attract the best talent – flexibility, autonomy, an organisational culture based on trust, and a clearly communicated company mission are becoming key.

In summary, for contemporary students, work is ceasing to be a goal in itself and is becoming a tool for building a fulfilling, balanced and meaningful life.

It should be emphasized, however, that a limitation of the present study lies in its review-based character, relying on an analysis of the existing literature, which restricts the possibility of direct verification of the relationships presented within specific student populations.

The analysis also reveals several important research gaps that require further investigation. In particular, there is a need for more cross-cultural comparative studies, analyses of differences between fields of study, and longitudinal research examining how students' career preferences evolve over time.

Accordingly, further empirical research is recommended in order to enable a more in-depth examination of the identified relationships and their contextual determinants.

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THE ROLE OF TECHNOLOGICAL INNOVATIONS IN SHAPING THE QUALITY OF DENTAL SERVICES

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Purpose: The aim of the article is to identify the role of technological innovations in shaping the quality of dental services and to determine their impact on the functioning of dental enterprises.
Design/methodology/approach: The study was based on a qualitative in-depth interview conducted with the owner of a dental enterprise and an analysis of documentation related to implemented technological solutions and digitalization processes.
Findings: The results indicate that technological innovations contribute to improving diagnostic precision, increasing service quality, enhancing organizational efficiency, and strengthening the competitive position of dental enterprises.
Research limitations/implications: The main limitation of the study results from its qualitative character and the inclusion of only one dental enterprise, which may limit the possibility of generalizing the findings to the entire sector.
Practical implications: The obtained results may support dental enterprises in planning technological investments and implementing digital solutions aimed at improving service quality and organizational effectiveness.
Social implications: The development of technological innovations in dentistry may contribute to improving patient comfort, increasing access to modern diagnostic methods, and enhancing the overall quality of healthcare services.
Originality/value: The added value of the article lies in combining technological, organizational, and quality-related perspectives in the analysis of the functioning of contemporary dental enterprises.
Keywords: technological innovations; dental services; service quality; digital dentistry; healthcare management.
Category of the paper: research paper.

1. Introduction

Modern dental companies are facing the conditions of dynamic technological changes. They have to face increasing competition and increasing patient expectations regarding the quality of the services provided. The development of modern diagnostic technologies, digital medical records management systems and advanced treatment methods makes technological innovations one of the important factors of competitiveness of enterprises in this industry. They affect the efficient functioning of dental facilities. The speed of service delivery, patient comfort, diagnostic precision and the level of organization of the company's work are also becoming increasingly important. The scientific literature emphasizes that the technological development of modern dentistry affects the quality of services provided, as well as building the competitive advantage of enterprises operating on the medical services market.

The issues raised are of significant importance both in the scientific and practical dimensions. The continuous development of digital medical technologies, process automation and solutions based on artificial intelligence even forces the need to conduct an analysis of the impact of technological innovations on the quality of dental services and on the organization of the functioning of companies in the medical industry. Despite the growing importance of modern technologies, there is still a noticeable shortage of research relating to the practical impact of implemented technological solutions on the quality of patient service and the efficiency of dental facilities. Therefore, it seems reasonable to undertake research that allows for the identification of the relationship between the level of technological innovation and the quality of dental services provided.

The aim of the article is to identify the importance of technological innovations in the process of shaping the quality of dental services and to determine the impact of modern technological solutions on the functioning of a company operating in the dental industry. In the first part of the study, theoretical aspects related to the quality of dental services and the role of technological innovations in modern dentistry were presented. Next, the methodological assumptions of our own research were presented. The results of a qualitative in-depth interview conducted with the owner of a dental company were presented. In the next part, the results obtained were analyzed. Then, conclusions, practical recommendations, limitations of research and future research directions were formulated. The added value of the article is an attempt to combine technological, organizational and qualitative perspectives in the analysis of the functioning of modern dental enterprises.

1.1. Shaping the quality of dental services

Care for the high quality of dental services can be considered one of the important areas of functioning of modern medical enterprises. In times of growing health awareness of society and increasing patient expectations, the effectiveness of treatment is becoming extremely important.

At the same time, the way the process of providing services is organized becomes equally important. For this reason, the availability of modern diagnostic methods and a high level of patient service are extremely important. The quality of dental services remains a complex category. It covers both the clinical, organizational and social dimensions. In the scientific literature, opinions can be found indicating that the level of quality of dental care has a direct impact on the quality of life of patients, their sense of security and the regularity of use of medical services (Goettems et al., 2012; Perazzo et al., 2017; Do, Spencer, 2007). At the same time, effective prevention and an appropriate level of dental care can reduce the occurrence of health problems among children and adolescents (Herndon et al., 2015; Paula et al., 2016). However, there are still barriers that make it much more difficult to use dental services. This becomes a consequence of the limited availability of services, the level of health awareness and the social situation of patients (Farlina, Maharani, 2018; Mouradian et al., 2000; Curi et al., 2018; Bastani et al., 2021; Mousa et al., 2026).

Modern dental companies are increasingly basing the development of service quality on the implementation of modern technologies. They provide organizational solutions that support the process of treatment and patient service. The development of digital diagnostics, electronic medical record systems and tools supporting the management of medical processes increases the efficiency of dental facilities. However, at the same time, the assessment of the quality of dental services may refer to both the results of treatment and the level of organization of health services. It can also be a consequence of the availability of services for patients (Mahrous et al., 2016; Righolt et al., 2019; Choi et al., 2022). The spatial accessibility of dental facilities is also of significant importance. It affects the perceived quality of care. It affects the ability of different social groups to use medical services (Chung, Chan, 2021). The need to take into account the needs of groups particularly vulnerable to health exclusion is also increasingly emphasized. Such a group includes m.in children requiring specialized dental care (Bastani et al., 2021).

Shaping the quality of dental services should be considered as a process that requires continuous adaptation of enterprises' operations to technological, organizational and social changes. High quality of services is also increasingly identified with the effectiveness of communication, the time-of-service delivery, patient comfort and the company's ability to implement innovative solutions. It is important that modern models of assessing the quality of medical services increasingly take into account the patient's perspective. They must also take into account the level of satisfaction resulting from contact with a medical facility (Dopeykar et al., 2018; Reich et al., 2018). This means that modern dental companies, which operate in the conditions of the modern economy, should treat the quality of services as one of the basic elements of building a competitive advantage and long-term organizational development.

1.2. Technological innovations in dental services

The development of technological innovations should keep up with the directions of changes that are taking place in modern dental services. Technological progress includes both the development of modern diagnostic and therapeutic methods. It is also important to implement digital solutions that support the organization of the work of medical facilities. The literature emphasizes that modern dentistry is increasingly based on advanced imaging technologies, digital treatment design, and automation of selected clinical processes (DaSilva et al., 2022; Zimmermann, Seitz, 2023). It is also noted that technological innovations are groundbreaking. They have an impact on changing the existing models of providing dental services (Edelstein, 2020; Joda et al., 2021). Particular importance is attached to the development of digital technologies. They increase the precision of treatment, shorten the time of service delivery and improve the quality of diagnostics (Alqahtani, 2024; Khojimurodov, 2021). It is also indicated that the development of innovative dental technologies is important in the context of an ageing population and the growing health needs of the elderly (Hartshorn, Nair, 2023).

Solutions based on digital technology, artificial intelligence and computerization of medical processes are becoming increasingly important in dental services. The implementation of digital dental technologies is determined by both economic and organizational conditions. It also depends on the competence of medical staff (Stakhanskyy, 2025; Alotaibi, Kassim, 2023). The development of artificial intelligence and analytical tools improves diagnostics. In addition, it supports clinical decision-making (Reis et al., 2023). At the same time, it is pointed out that the process of digitization of dental services faces certain barriers. These are related to, among other things, the costs of implementations, the need for staff training and the level of acceptance of new technologies by dentists (van der Zande et al., 2013). Modern dentistry is increasingly using solutions related to the Internet of Things (IoT). Thanks to their use, it is possible to integrate medical devices. IoT also allows for monitoring treatment and diagnostic processes (Balaji Ganesh, Sugumar, 2021). It also highlights the growing role of digital technologies in public health and improving the accessibility of dental services (Srivastava et al., 2023).

Technological innovations currently affect both the course of the treatment process, but also the functioning and development of the market for the entire medical services. The literature indicates that modern dentistry is becoming one of the most dynamically developing fields of medicine. It offers a wide range of opportunities for professional development. It also contributes to cooperation with the technological and industrial sectors (Seif et al., 2024). At the same time, it is emphasized that the development of modern technologies forces the need to adapt dental facility management models to new market conditions and growing patient expectations (Manalili, Swanson, 2025). Certainly, therefore, the future of dental services will be increasingly associated with the development of digital treatment methods and the automation of clinical processes. It will also depend on the integration of modern diagnostic

and communication systems (Blum, 2024). This means that the ability to implement technological innovations is now becoming one of the key factors affecting the competitiveness and quality of functioning of companies operating in the dental industry.

2. Methods

The aim of this study was to identify the importance of technological innovations in the process of shaping the quality of dental services and to determine the impact of modern technological solutions on the functioning of a company operating in the dental industry. Efforts were made to determine the role of modern diagnostic technologies, digitization of processes and work organization in improving the quality of services provided.

The paper adopts a research hypothesis. It assumed that the implementation of technological innovations increases the quality of dental services and increases the competitiveness of the company operating in the dental industry. In order to verify the hypothesis, the following research questions were formulated: (1) Do technological innovations affect the quality of dental services? (2) What is the importance of modern diagnostic technologies in the process of treating patients? (3) Does the digitization of organizational processes affect the efficiency of the company's operation? (4) How do technological innovations affect patient satisfaction? (5) Do technological investments affect the competitiveness of a dental company?

The study used the method of qualitative in-depth interview. It was carried out with the owner of a company that operates in the dental industry. The interview took on a partially structured character. It was carried out on the basis of a prepared research scenario. He referred to issues related to the implementation of modern technologies, the organization of processes and the quality of services provided. In addition, an analysis of the company's documentation was carried out. It concerned the implemented technological solutions, the scope of services provided, the diagnostic methods used and the processes of digitization of the facility.

The obtained results were subjected to qualitative analysis. Then they were presented in the form of a funnel chart. This chart allowed to illustrate the assessment of the impact of technological innovations on selected areas of the dental company's operation.

3. Results

In accordance with the purpose of this article, a qualitative in-depth interview was conducted with the owner of a company operating in the dental industry. The aim of the study was to identify the importance of technological innovations in the process of shaping the quality of dental services and to learn opinions on the impact of modern technological solutions on the functioning of the company. The interview was partially structured. It was carried out on the basis of a prepared research scenario.

First, the respondent was asked about the reasons for the implementation of modern technologies in a dental company. The answer was primarily indicated by the growing expectations of patients, the need to increase the precision of diagnostics and the need to build a competitive advantage on the medical services market.

Next, they were asked about the impact of innovative diagnostic devices on the quality of services provided. The respondent emphasized that the implementation of modern computed tomography and digital imaging methods has significantly increased the accuracy of diagnosis. It also enabled faster therapeutic decision-making.

Another issue concerned the impact of technology on the level of patient satisfaction. The response indicated that patients pay special attention to the modernity of the office. But also important is the comfort of treatment and the ability to perform comprehensive diagnostics in one place, which increases their trust in the company.

In the further part of the interview, they were asked about the importance of digitization of medical records and computerization of the facility. The answer was emphasized that the implementation of electronic patient records improved the organization of work, the flow of information and the management of the treatment process.

Next, the problem of the impact of technological innovations on the organizational efficiency of the company was raised. The respondent stated that modern technological solutions have contributed to shortening the time of service delivery, reducing the number of organizational errors and improving communication between staff.

Another issue concerned the impact of technological investments on the competitiveness of the company. In response, it was stated that the implementation of innovative technologies makes it possible to acquire new patients. It also allows you to build the image of a modern and professional dental facility.

Later in the interview, they were asked about the changing expectations of patients towards dental services. In response, the respondent stated that modern patients expect high quality treatment above all. However, they also expect quick diagnostics, comfort of use and access to modern medical technologies.

In the last part of the interview, the importance of continuous technological development for the future of the company was asked. The respondent emphasized that systematic investment in innovative solutions is a condition for maintaining the high quality of services and further development of the company operating in the dental industry. Table 1 presents the results of an interview on the role of technological innovations in shaping the quality of dental services.

Table 1.
Results of a qualitative interview on the role of technological innovations in shaping the quality of dental services

Question	Answer	Importance for service quality
What influenced the implementation of new technologies?	Growing patient expectations	Increasing the competitiveness of the facility
How does modern diagnostics affect treatment?	Improves the accuracy of diagnosis	Improved service efficiency
How do patients rate innovative solutions?	They positively evaluate comfort	Increase patient satisfaction
What is the importance of digitization of documentation?	Improves work organization	Faster flow of information
Do technologies affect work efficiency?	Reduce service delivery time	Better organization of processes
How do technology investments affect a company?	They build a competitive advantage	Recruiting new patients
How are patient expectations changing?	They expect modern services	The need for continuous development
What is the importance of further investments?	They condition the development of the company	Maintaining high quality services

Source: Own study.

Figure 1 presents an assessment of the importance of technological innovations in the process of shaping the quality of dental services. The results obtained indicate that the impact of modern technological solutions on the quality of services provided and diagnostic precision was rated the highest. High values were also attributed to the importance of technology in building the company's competitive advantage. This proves the growing importance of innovation in the functioning of entities operating in the dental industry. The respondent also drew attention to the importance of technology for improving the organization of processes and increasing patient satisfaction. A relatively lower rating was given to the area related to the flow of information. Despite this, the positive impact of the implemented solutions is also noticeable in this case. The results obtained confirm that technological development is one of the important factors influencing the improvement of the standard of dental services and increasing the efficiency of the company's operation.

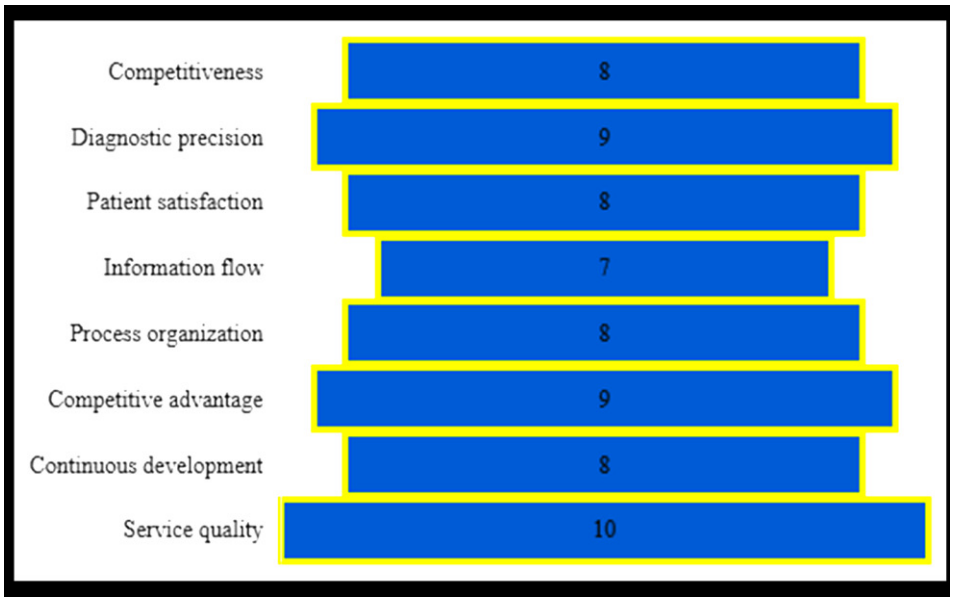

Figure 1. Assessment of the importance of technological innovations for the quality of dental services. Source: Own study.

Figure 1 presents the assessment scores on the horizontal axis and the analyzed areas of technological impact on the vertical axis. Figure 1 indicates that technological innovations play a significant role in improving the quality of dental services. The highest ratings were assigned to the impact of modern technologies on service quality, diagnostic precision, and building the competitive advantage of the company. The results also show that technological solutions contribute to better work organization, increased patient satisfaction, and improved efficiency of the dental facility.

4. Discussion

On the basis of the conducted research, several important conclusions can be drawn concerning the role of technological innovations in the operations of enterprises operating in the dental industry. Based on the results obtained, it can be indicated that modern technological solutions primarily improve the quality of services provided. They also increase diagnostic precision. Particular importance was given to modern imaging methods and digital solutions. These technologies strongly support the treatment process. The implementation of advanced technologies allows for more accurate treatment planning, as well as shortening the time of service delivery and reducing the risk of diagnostic errors.

The conducted research also allows us to notice that technological development affects the entire organization of the functioning of a dental company. The computerization of processes and the implementation of electronic medical records contribute to the improvement of the flow of information. In addition, its implementation leads to improved work organization and

increased efficiency of the activities carried out. Attention was also paid to the growing expectations of patients towards modern medical facilities. Currently, the quality of services is increasingly determined not only by the undoubted effectiveness of treatment, but also by the level of technological advancement of the company, the comfort of service and the availability of comprehensive diagnostics in one place.

In conclusion, it can be stated that investing in technological innovations is decisive for building a company's competitive position on the dental services market. The dynamic development of medical technologies makes it necessary to systematically adapt operations to changing market conditions and patient expectations. Therefore, it can be said that modern technologies are currently one of the basic factors supporting the development of dental companies and raising the standard of services provided.

The results of the conducted research are consistent with the findings of other researchers. They indicate that technological innovations improve the quality of dental services, increase diagnostic precision and improve the organization of the work of medical facilities. In its own study, the importance of technology for the quality of services provided, the accuracy of diagnostics and building the company's competitive advantage were rated the highest. Similar conclusions were presented by DaSilva et al. (2022). These researchers have shown that the development of digital dentistry, modern imaging methods and advanced diagnostic technologies improves the effectiveness of treatment and the organization of the therapeutic process. Also, Joda et al. (2021) highlight that technological innovation is leading to the transformation of modern dentistry. They affect both clinical practice and the functioning of medical enterprises. In turn, Zimmermann and Seitz (2023) point out that the development of digital medical technologies increases the efficiency of service provision and changes the way of communicating with patients.

The results obtained also coincide with research that deals with the role of digitization of organizational processes and concerns the implementation of electronic medical records. In our own study, it was indicated that the computerization of processes improves the flow of information. It also improves the organization of the company's work. A similar position is presented by van der Zande, Gorter and Wismeijer (2013). They point out that the implementation of digital technologies in dentistry can contribute to improving the efficiency of the functioning of facilities. However, this process is also associated with the need to overcome organizational and competence barriers. Also, Reis et al. (2023) highlight the growing importance of artificial intelligence and digital tools in diagnostic and organizational processes. The results obtained are also partially in line with the findings of Alotaibi and Kassim (2023). They point out that the effectiveness of the implementation of modern technologies depends on the level of technological advancement of the company, as well as on the competence of the staff and the organizational readiness of the facility to adapt new solutions.

The study identified that technological investments may support competitive advantage and patient acquisition. However, no quantitative evidence concerning increases in patient numbers or market performance after the implementation of technological innovations was included. Future studies should therefore incorporate measurable economic and organizational indicators.

The lower assessment of information flow may indicate that, despite the implementation of digital technologies, some organizational and communication processes still require further integration and optimization within the dental facility.

5. Conclusions

On the basis of the conclusions obtained, recommendations can be formulated for enterprises operating in the dental industry. They concern the need for systematic implementation of technological innovations. Because it is these innovations that support the process of diagnosis and treatment of patients. Particular importance should be given to investments in modern diagnostic devices, digital solutions and IT systems improving the organization of the facility's work. The implementation of modern technologies can contribute to increasing the precision of the services provided. This results in improved efficiency of the company's operation and shortened patient service time. The development of electronic medical records and tools supporting the flow of information within the company is also important.

On the basis of the conducted research, it can also be concluded that companies from the dental industry should treat technological development as an element of a long-term strategy to build a competitive advantage. Constant changes that are constantly and dynamically taking place in the medical services sector make it necessary to constantly adapt the offer to the growing expectations of patients. They are increasingly paying attention to the level of modernity of the facility and the availability of advanced diagnostic methods. It also seems reasonable to systematically improve the competences of staff in the use of new technologies. It is also necessary to monitor changes in the dental services market. Such activities can be conducive to maintaining the high quality of services. They are also conducive to strengthening the company's position on the competitive medical market.

Future research directions may focus on an in-depth analysis of the impact of individual medical technologies on the efficiency of dental companies and on the level of patient satisfaction. It also seems reasonable to expand the research to a larger number of entities operating in the dental industry. This would allow for comparative analyses between companies with different levels of technological advancement. An interesting research area may also be the assessment of the impact of artificial intelligence, digital diagnostic systems and process automation on the quality of medical services and the organization of staff work. In the future, it is also worth taking into account the perspective of patients. It is also worth conducting

quantitative research. This would make it possible to identify the relationship between the level of innovation of the company and the perceived quality of the dental services provided.

Future research could incorporate measurable indicators related to service quality and organizational efficiency, such as patient satisfaction level, service delivery time, diagnostic accuracy, or effectiveness of information flow. This would allow for broader quantitative verification of the impact of technological innovations on dental enterprises.

The limitation of the conducted research was primarily the qualitative nature of the analysis. Restrictions may also include the inclusion of one company operating in the dental industry in the examination. The results obtained therefore reflect the experience and perspective of a particular entity. This may limit the possibility of their full generalization to the entire industry. A certain limitation is also the subjective nature of assessments relating to the impact of technological innovations on the quality of services and on the functioning of the company. The continuous development of medical technologies is also important. It means that some of the analyzed solutions may change or develop in a relatively short time. Despite the indicated limitations, the conducted research allowed to identify significant relationships related to the role of technological innovations in the operations of dental enterprises.

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ORGANIZATION AND MANAGEMENT SERIES NO. 251

IMPACT OF QUALITY ON THE ECONOMIC CONDITION OF SERVICE ENTERPRISE – CASE STUDY USING THE SERVQUAL METHOD

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Purpose: The aim of the article is to assess the service quality of a chosen enterprise od the CEP sector using the Servqual method and statistical research. The quality assessment constitutes the basis for drawing conclusions about the possible concatenation between the quality of services and the economic condition of the analyzed organization.
Design/methodology/approach: A critical analysis of literature in the field of service quality and the chosen methods, an examination of documents concerning a certain company, and a diagnostic survey method conducted among customers of a chosen courier company and statistical research have been used.
Findings: Customers are dissatisfied with the quality of services offered by this operator. According to the traditional Servqual methodology, a quality gap was identified between expectations and the service received. All the most important quality characteristics relate to the core of the service. In order to reduce the risk associated with random selection of the research sample and to isolate the answers obtained from respondents who are actual customers of the analyzed organization, correlation coefficients were calculated between the frequency of using the offer and the assessment of the importance and perception of quality determinants. In the majority of cases, frequent use of a given service is negatively correlated with the perceived importance of specific service quality attributes. The type of service used by an operator's customers does not appear to significantly influence the evaluation of individual service quality dimensions; on the contrary, it tends to diminish their perceived relevance.
Research limitations/implications: The results obtained are a valuable source of information for both practitioners (managers of courier companies) and theoreticians (researchers analyzing the processes taking place in the CEP sector and service quality).
Practical implications: The study has practical applications for service sector companies. It is particularly relevant for business practitioners in the CEP industry, as a basis for strategic analysis and holistic quality management.
Originality/value: The paper fills the identified literature gap. It has been shown that there is a wide range of theoretical studies and research in the field of service quality and analysis of the courier services. The conducted research indicated that there is a lack of analysis of the extensive use of the Servqual method in assessing the quality of postal services and statistical research based on this method, resulting in reflection on the links between quality and the economic condition of the company.
Keywords: CEP, service quality, the Servqual.
Category of the paper: Research article.

1. Introduction

Modern society functions within a highly volatile environment. The continuous and rapid changes in socio-economic processes significantly impact the operation of the global economy, individual nations, various economic sectors, and society as a whole. Although the assessment of these phenomena is highly subjective, there is no doubt that modern enterprises operate amidst intense competition, considered not only regionally and nationally but also, in many cases, globally (Wirtz, Tuzovic, Ehret, 2015).

As one might expect, competition is intense in the services sector, whose importance in the global economy is characterized by a growing trend, closely linked to the economic development of individual countries. One of the characteristics of this sector is its high degree of fragmentation. This means that individual services are provided by various economic sectors, and the number of their suppliers and customers is constantly growing (Kwiatkowska, 2015). To differentiate themselves in the market, strengthen their competitive position, and simultaneously strive to maximize profits, many entities operate in accordance with various modern management philosophies and approaches.

In addition to the most popular, traditional price competition, competitive methods in today's market also include non-price competition, including quality. Research shows that quality is a key factor in competitiveness. Achieving an appropriate level of quality enables competition in other areas, and competitiveness itself consists of a number of determinants of varying importance, yet interdependent in some way (Sumardi, Fernandes, 2020).

The possibility of gaining a competitive advantage through quality-related activities is possible when: the quality of a given company's services is higher than that of its competitors; customers rate the quality of a given company's services higher than that of its competitors; and improving quality is linked to the ability to set higher prices for services (Kaur, Kaushik, 2022).

In summary, quality in the services sector is extremely important. This importance stems from the characteristics of the modern economy, in which the services sector plays a significant and ever-increasing role in shaping economic indicators. These characteristics translate into the level of competition in the sector, and both traditional and recent competitiveness assumptions point to quality as a fundamental and still difficult-to-achieve competitive tool (Gillies, 2015).

2. Quality and postal services

Until 1991, postal services in Poland were exclusively delivered by a single provider. However, starting in 2003, the postal market began to undergo gradual liberalization following the implementation of new legislation. 98 postal operators submitted reports for 2024. The value of the Polish postal services market in 2024 amounted to PLN 18.69 billion (an increase of PLN 2.15 billion year-on-year and a growth rate of 13.0%). The overall volume of postal services increased by 110 million items (5.4%). Among the main postal services, letters, parcels, and courier shipments are the most prominent, along with money orders and marketing mail. Courier delivery remains the primary postal service, and has seen significant growth with the development of e-commerce. Compared to 2023, the volume of courier shipments increased by 15.3% and revenues by 16.1%. In 2024, these shipments accounted for 73.3% of the postal market value and 56.6% of the total volume of postal services (UKE Report, 2024). These data indicate the importance of interest in the postal services market among scientists and business practitioners.

In the last calendar year, the analyzed operator recorded a decline in both domestic and international volume (by 7% and 6.5%, respectively). It is worth noting that the analyzed operator's volume decreased by 5.9%, while maintaining a high share of the total volume (45%). Despite the increase in revenues from postal operations (related to price increases), this operator lost its share of revenues relative to its competitors. Furthermore, a 6.7% decline in employment was identified, the highest among its competitors (UKE Report, 2024).

Due to the potential for growth in selected postal service segments (primarily courier services), reports highlight the sector's attractiveness and strong price competition. Ensuring high-quality service is a response to the limited potential for further price pressure.

Quality is a complex and dynamic concept that is difficult to define universally for two main reasons (Urban, 2007). First, it evolves in response to changes in human development—social, technological, and otherwise—which in turn influence both the nature of quality (as it pertains to products, services, or quality of life) and how it is perceived. Second, quality is inherently subjective and shaped by a wide range of determinants, making its assessment and definition context-dependent (Gajewska, 2019, Teklay et al, 2023).

Service quality is largely determined by intangible factors, which are evaluated by individuals with diverse perspectives and expectations (Gawahi, Hosseini, Moheimani, 2023). These evaluations are based on selected quality determinants, which themselves are drawn from a broad array of possible attributes applicable to a product or service. Such attributes may include price, product functionality, warranty duration, and transaction convenience; for services, additional factors such as the durability of the service outcome, the perceived expertise of the service provider, and the quality of interaction between the service user and provider also play a role. The assessment of quality is inherently complex, as it is influenced

by the evaluator's knowledge, prior experiences, and perception of the company. Furthermore, the relative importance of specific quality determinants varies across individuals, adding to the subjectivity of the evaluation process (Solin, Curry, 2023, Stoma, 2012).

3. Research methodology

The study was conducted using the diagnostic survey method. The diagnostic survey method (using a survey technique as the main formula), also known as the survey research method, involves obtaining answers to a set of questions relevant to solving the research problem from precisely defined individuals (respondents characterized by a set of selected characteristics). Surveys are characterized by a lack of dynamic interaction between the researcher and the person being surveyed (Zimba, Gasparyan, 2023).

The questionnaire contained two parts: a metric (including age, gender, education) and a substantive part consisting of questions about containing questions about the assessment of the importance and perceived quality of chosen factors, selected based on the Servqual methodology.

The Servqual method, developed by A. Parasuraman, V.A. Zeithaml, and L.L. Berry, is widely recognized as one of the most universal approaches to measuring service quality. It is grounded in the quality gaps model, which identifies four internal gaps and one external gap that collectively contribute to a decrease in perceived service quality (Kowalik, 2019). The assumptions of the Servqual method focus on the fifth gap. This approach evaluates the difference between customers' expectations and their perceptions of service quality by conducting a detailed analysis, which involves the use of a specially designed questionnaire. The questionnaire is designed by formulating statements for each service quality attribute, assessed from two perspectives: perception and expectation. Each statement is categorized under one of the five quality dimensions (Ghifari, Astanti, 2025):

- tangibles – physical facilities and equipment (T1 – attractiveness of institution, T2 – modernity of equipment, T3 – staff's appearance, T4 – availability of materials),
- reliability – (R1 – punctuality of service delivery, R2 – faultlessness of service delivery, R3 – staff's help in problem-solving, R4 – compliance with the offer accuracy and dependability in service delivery),
- responsiveness – willingness to assist customers (RP1 – efficiency of service delivery, RP2 – transmission of all the information, RP3 – immediate response to requests),
- assurance – employees' competence and courtesy (A1 – staff's competence, A2 – staff's politeness, A3 – staff's trust inspiration, A4 – ensuring the security),

- empathy – personalized attention to customers (E1 – individualized treatment, E2 – willingness to help, E3 – paying attention to customers, E4 – customers' needs understanding).

Respondents rated these statements using a Likert scale, most commonly a five-point scale, where 5 represents "strongly agree" and 1 represents "strongly disagree". Following this, the importance of each quality dimension is assessed.

The collected data were processed in a descriptive form and using statistical tests. Spearman correlation coefficients were used in the paper. The significance level was set at 0.05. The study involved about one thousand customers of the analyzed company (Table 1) and was conducted from 2025 January to June in online form. The sample was selected purposively. Before completing the questionnaire, respondents confirmed that they had experience as a customer of the company being analyzed.

Table 1.
Characteristics of respondents

Customers									
Gender [%]		Age [%]				Education [%]			
Male	Female	18-24	25-39	40-59	60<	primary	vocational	secondary	higher
49.74	50.26	14.17	31.27	38.51	16.05	0.84	16.68	52.15	30.33
Total: 100		Total: 100				Total:100			

Source: Author's calculations.

In light of the considerations undertaken so far during the research process, the following research questions were asked: Does the service quality influence on economic condition of the postal operator? How does the frequency of use of the indicated postal services translate into the assessment of the importance and perception of individual quality determinants? The aim of this study is therefore to show the impact of service quality on the economic condition of the postal operator.

4. Research results and discussion

The respondents assessed the presented attributes in two aspects: perception (how is it?) and expectation (how should it be?) and gave weights to each dimension (the sum of dimensional weights equals 1). Partial results, showing the average of each quality attribute (gap scores), are presented in table 2.

Table 2.
The Servqual's gap score

Dimension	Attribute	Expectation score	Perception Score	Gap score
tangibles	T1	4.034	3.680	-0.354
	T2	4.034	3.458	-0.576
	T3	4.230	3.863	-0.547
	T4	4.269	3.794	-0.475
reliability	R1	4.506	3.560	-0.946
	R2	4.497	3.859	-0.638
	R3	4.414	3.731	-0.683
	R4	4.492	3.961	-0.531
assurance	A1	4.434	3.891	-0.543
	A2	4.335	3.749	-0.586
	A3	4.251	3.681	-0.570
	A4	4.189	3.707	-0.482
responsiveness	RP1	4.352	3.474	-0.878
	RP2	4.220	3.692	-0.528
	RP3	4.275	3.652	-0.623
empathy	E1	4.003	3.463	-0.540
	E2	4.178	3.497	-0.681
	E3	3.902	3.522	-0.380
	E4	4.046	3.473	-0.573

Source: Authors' calculations.

According to the partial results, initial conclusions point to higher expectations from perception. All of the average attributes results are negative numbers. Table 3 presents final results of the Servqual method.

Table 3.
The Servqual score

Dimension	Average of dimension	Importance weight	Weighed score	Average
tangibles	-0.488	0.129	-0.063	-0.113
reliability	-0.700	0.251	-0.176	
assurance	-0.545	0.214	-0.117	
responsiveness	-0.676	0.179	-0.121	
empathy	-0.545	0.164	-0.089	

Source: Authors' calculations.

The presented data indicate an insufficient level of quality of the postal operator in this study. The averages of each dimension are values below 0. The most important dimension of postal service quality is reliability, the least one- tangibles. The correction of the indicator by weights contributed to the calculation of the weighed Servqual indicator, which assumed the value -0,113. In accordance with the principles of the Servqual method, negative value means too low quality. The implementaion of improvement in some areas of quality may increase customers' assessment of perception. The highest gap score, which definitely stands out among the determinants, concerns the feature R1 – punctuality of service delivery (-0.946) and RP1 – efficiency of service delivery (-0.878). Moreover, these dimensions are characterized by the highest weight significance (place 1 and 3). These determinants concern the core of the postal service, which indicates a significant problem with the level of quality.

Due to the random selection of the research sample, to further deepen the study, respondents were also asked about their frequency of use of various postal services provided by the analyzed operator. Correlation coefficients were then calculated between the frequency of use of individual postal services and the assessment of the importance (Table 4) and perception (Table 5) of the quality of selected determinants.

Table 4.
Values of correlation coefficients between the use of particular services and the assessment of the importance of Servqual features of service quality

Pair of variables	parcels	courier shipments	financial services	sale of products related to postal services	sale of products not related to postal services
T1	**-0.068**	-0.016	-0.008	**-0.069**	0.027
T2	**-0.107**	**-0.136**	**-0.127**	-0.049	-0.008
T3	**-0.093**	0.050	**-0.158**	**-0.080**	**-0.066**
T4	**-0.092**	-0.029	**-0.088**	**-0.103**	-0.009
R1	-0.046	-0.060	**0.064**	0.025	0.048
R2	**-0.110**	-0.014	**-0.165**	-0.014	-0.003
R3	**-0.074**	**-0.066**	-0.018	-0.029	0.010
R4	-0.031	**-0.120**	-0.012	0.044	-0.006
A1	-0.005	**-0.116**	**-0.204**	-0.061	**-0.077**
A2	-0.020	**-0.123**	**-0.147**	-0.051	-0.018
A3	**0.076**	0.042	0.001	0.018	0.014
A4	**0.072**	0.010	-0.033	-0.029	-0.042
RP1	-0.061	**-0.091**	**-0.168**	-0.009	-0.024
RP2	-0.005	-0.018	**-0.085**	-0.045	**-0.071**
RP3	0.029	0.036	0.009	-0.022	0.000
E1	0.046	**0.075**	0.010	-0.045	0.006
E2	0.049	-0.019	**-0.213**	-0.035	**-0.077**
E3	0.049	-0.024	**-0.073**	-0.049	-0.008
E4	-0.014	-0.038	-0.039	-0.061	-0.011

Source: Authors' calculations.

In most cases, regular service use is negatively associated with the assessment of the importance of individual service quality characteristics. Five statistically significant correlations were identified with respect to the assessment of the importance of quality by respondents using parcel services. The positive correlation here concerns two aspects: instilling trust ($rs = 0.076$; $p = 0.019$) and a sense of security ($rs = 0.072$; $p = 0.026$). In six cases, people sending/receiving courier parcels rated the importance of service quality significantly lower, and only in the case of individual treatment did they significantly more often indicate the importance of this characteristic ($rs = 0.075$; $p = 0.021$). Users of financial services are by far the least demanding customers. In as many as 10 cases, a statistically significant negative correlation was confirmed between the frequency of use of this type of service and the assessment of the importance of individual service quality characteristics. The more frequently these people use financial services, the less they pay attention to quality. The only noteworthy factor in this group was service time ($rs = 0.064$; $p = 0.050$). Sales of products related to postal services had almost no impact on the assessment of the importance of postal service quality. Only three statistically significant negative correlations were observed. In the case of sales of

products unrelated to postal services, statistically significant negative correlations were found for four features. In summary, it can be said that the type of service used by the operator's customers does not influence the assessment of the importance of individual service quality features; in fact, it weakens their significance.

Table 5.
Values of correlation coefficients between the use of particular services and the assessment of the perception of Servqual features of service quality

Pair of variables	parcels	courier shipments	financial services	sale of products related to postal services	sale of products non related to postal services
T1	**0.111**	0.015	**0.260**	**0.127**	**0.098**
T2	**0.133**	0.014	**0.212**	**0.123**	**0.069**
T3	0.061	-0.003	**0.214**	**0.084**	**0.076**
T4	**0.102**	0.007	**0.223**	**0.118**	**0.086**
R1	**0.094**	-0.005	**0.251**	**0.094**	**0.104**
R2	**0.092**	0.034	**0.280**	**0.127**	**0.136**
R3	-0.025	**-0.134**	**0.088**	0.039	**0.064**
R4	0.011	0.002	**0.154**	0.011	**0.074**
A1	**0.125**	0.044	**0.304**	0,048	**0.116**
A2	0.024	**-0.089**	**0.126**	-0.007	0.058
A3	0.038	-0.045	**0.167**	0.036	**0.087**
A4	0.011	**-0.102**	0.043	-0.044	0.007
RP1	**0.068**	**-0.114**	**0.088**	0.004	0.012
RP2	**0.126**	-0.003	**0.240**	0.022	**0.086**
RP3	**0.160**	0.017	**0.242**	0.049	**0.111**
E1	**0.079**	**-0.095**	**0.172**	0.053	**0.111**
E2	**0.101**	0.010	**0.222**	**0.069**	**0.111**
E3	**0.087**	-0.017	**0.138**	0.029	**0.069**
E4	**0.078**	-0.030	**0.167**	0.052	**0.090**

Source: Authors' calculations.

As expected, most regular users of the operator's services rate the quality of these services highly. A statistically significant positive correlation was observed for 13 characteristics for those using parcel sending/receiving services, 16 for those using non-postal product sales services, the highest correlation (18) for those using financial services, and the lowest (7) for those using postal product sales services. However, in contrast to these assessments, five negative correlations appear between the frequency of using courier services and the assessment of service quality, including receiving help in case of problems ($rs = -0.134$; $p < 0.001$), staff courtesy ($rs = -0.089$; $p = 0.006$), sense of security ($rs = -0.102$; $p = 0.002$), efficiency and speed of service ($rs = -0.114$; $p < 0.001$) and individual treatment ($rs = -0.095$; $p = 0.003$).

5. Conclusions

Contemporary enterprises function within a highly competitive environment. Although individual industries exhibit substantial differences, organizations across diverse sectors are progressively adopting unconventional approaches as a means to achieve differentiation and maintain a competitive advantage.

Moving on to the summary of the conducted research, it can be stated that customers are dissatisfied with the quality of services offered by this operator. According to the traditional Servqual methodology, a quality gap was identified between expectations and the service received. All dimensions received negative scores. The most important quality dimensions in the analyzed study were reliability and assurance. Among the most important determinants, respondents identified reliability factors, such as punctuality, faultlessness, staff assistance, and compliance with the offer. This means that all the most important quality characteristics relate to the core of the service. Among the ratings, the highest perceptions were identified for compliance with the offer, employees' competence and courtesy, and staff's appearance, but the gap score for each determinant was negative.

In order to reduce the risk associated with random selection of the research sample and to isolate the answers obtained from respondents who are actual customers of the analyzed organization, correlation coefficients were calculated between the frequency of using the offer and the assessment of the importance and perception of quality determinants. In the majority of cases, frequent use of a given service is negatively correlated with the perceived importance of specific service quality attributes. In summary, the type of service used by an operator’s customers does not appear to significantly influence the evaluation of individual service quality dimensions; on the contrary, it tends to diminish their perceived relevance. In addition, the majority of regular users of the operator’s services provide a favorable evaluation of service quality. This means that customers who regularly use this operator's services are satisfied with the quality of service. This leads to the next research question: what factors influence the negative opinions of customers who do not use or rarely use this operator's services?

Referring to the aim of the article, which was to assess the impact of service quality on the economic condition of the postal operator it can be concluded that service quality may be the determinant of the economic condition of the postal operator. Customers perceive the quality of service as unsatisfactory. This operator has a group of regular customers who indicate significantly higher perceived quality and lower expectations, but potential customers are negative about this operator's quality. They have significantly higher expectations and rate the actual quality significantly lower, which may mean they have abandoned using this operator's postal services, which, given the economies of scale, directly impacts its economic performance.

The study may be useful for the postal services industry and provide a basis for analyzing service quality among competitors. From an economic and management perspective, the study can serve as a basis for further, in-depth analysis and provide a framework for regional, national, and international comparisons.

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ARTIFICIAL INTELLIGENCE APPLICATION IN ENTERPRISE BASED ON BUSINESS MODEL CANVAS

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Purpose: This article aims to identify the business model canvas (BMC) areas in which enterprises most frequently implement artificial intelligence (AI) tools and to determine the structural and operational factors that determine their use.
Design/methodology/approach: This survey uses a mixed-methods study that combines a systematic literature review with a two-stage quantitative analysis. First, Z-tests and Chi-square tests examined nine BMC areas using a proportion test (50% population share) to evaluate AI tool prevalence. Second, 18 logit models explained the impact of structural and operational variables on AI use.
Findings: The proportion test results showed that in 2024, significant AI tool use was concentrated in key activities and value propositions. In 2025, customer relationships were added as another area with statistically significant AI use. Econometric research results showed that the implementation of an AI tool in one BMC area depends on its implementation in other areas.
Research limitations/implications: Limitations include the survey's geographic sample size and the evolving level of organizational awareness and knowledge regarding AI tools.
Practical implications: The proportion test results indicate that companies should prioritize implementing AI tools in value propositions, key activities, and customer relationships to improve efficiency and competitiveness. Econometric results indicate that the successive diffusion of AI in a single area of a business model generates network benefits, which can reduce psychological barriers and foster the effective adoption of AI tools within enterprises and increase employee competency.
Social implications: The application of AI tools in specific areas of business models can accelerate digital transformation in a broader context, improve user experience, and influence organizational and management practices.
Originality/value: Unlike other studies, a unique hybrid methodology was conducted based on a systematic literature review with a two-stage quantitative study consisting of simple statistical tests and a set of 18 logit models, which allowed for the identification of AI adoption locations and their mechanisms of diffusion in the business models.
Keywords: Artificial Intelligence, Business Model Canvas, value propositions, key activities, customer relationships.
Category of the paper: Research paper.

1. Introduction

Artificial intelligence (AI) tools are solutions based on interdisciplinary advances in computer science. The term "artificial intelligence" was coined by John McCarthy and presented at the Dartmouth Conference in 1956 (McCarthy, Minsky, Shannon, 1955). Kaplan and Haenlein (2019) define AI as "the ability of a system to correctly interpret data from external sources, learn from that data, and use that knowledge to perform specific tasks and achieve goals through flexible adaptation" (Kaplan, Haenlein, 2019). Key technological components of AI tools include machine learning algorithms, deep learning, fuzzy logic, evolutionary algorithms, swarm intelligence, large language models (LJMs) for processing structured and unstructured data, and computer vision (Sarker, 2021). Intermediate components include graphics processing units (GPUs), transistor processors (TPUs), and cloud computing infrastructure (Nikolić, Dimitrijević, 2022). Robotics and automation, including applications of the Industrial Internet of Things (IoT), are also important (Khang, Gupta et al., 2023; Rath, Khang, Roy, 2024). As a system, artificial intelligence (AI) has the "ability" to perform specific actions based on external "data". Data drives AI. The system's actions on this data allow it to learn to perform specific tasks and achieve goals in an adaptive manner, i.e., in a way that allows it to adapt to the conditions prevailing at a given moment. The challenge of today is undoubtedly the effective adaptation of AI tools and their effective operation in a system such as an enterprise. This is important, otherwise tensions may arise resulting from the strategic and operational assimilation of AI in enterprises. Current macroeconomic literature widely documents the impact of digital transformation (Śledziewska, Włoch, 2023; Westerman, Bonnet, 2014; Brynjolfsson, McAfee, 2014; Zuboff, 2019), including how advanced artificial intelligence algorithms change the structure, dynamics, and trade policy at the macro and global level (Śledziewska, 2025), gross domestic product (Nowakowski, 2026), or how they affect wages, income, productivity (Acemoglu, 2021), fiscal policy, taxation, and the stability of financial systems (Agrawal, Brynjolfsson, Korinek), divergence, and inequality (Cerutti, Pascual, Kido et al., 2025). However, there is still a deficit in empirical research on the adaptation of AI tools in specific areas of enterprise activity. Previous studies have often focused on AI adoption in its entirety (McElheran, Li, Brynjolfsson et al., 2024; McElheran, Yanf, Kroff, Brynjolfsson, 2026; Bonney, Breaux, Buffington et al., 2024; Bonney, Breaux, Dinlersoz et al., 2026), which often boiled down to the statement “AI-using firms”. Currently, this research approach is being practiced less and less, in favor of research that examines AI adoption in enterprises from the perspective of internal applications in various business areas of the organization (Pastor-Merino, Martínez-Barbero, Vicente, Domenech, 2026; Acemoglu, 2024). Therefore, the concept based on the BMC (Business Model Canvas) template can be applied to the study of AI adoption in individual areas of the business model. Such research can be carried out at the binary level, showing the progress of AI tool adoption in individual areas

of the business model. However, the problem of dynamics remains. Year-to-year (i.e., two-year) studies cannot capture this dynamics. With respect to the binary approach, a solution may be the use of proportion tests, which do not reflect year-to-year dynamics but show the ongoing change in the use of AI tools not only within the entire BMC template but also in its individual areas. It's important to remember that the market launch of tools like Chat GPT, Copilot, and Gemini is scheduled for the turn of 2022/2023, with practical implementation in enterprises expected in 2024-2025 (McKinsey & Company, 2025; Stanford University Human-Centered Artificial Intelligence, 2026; Alfaro, Cabrales, Roa et al., 2026; Liu, Wang, 2026). Therefore, capturing these dynamics requires a different perspective. By implementing the Business Model Canvas (BMC) template and thus applying it to the study of AI adoption in specific business model areas, it is possible to develop econometric models that can explain how the change in AI application in a given area depends on variables such as company size, business profile, sector type, and the number of areas in which AI tools have been adopted so far.

Taking the above into account, the aim of this article is to identify the areas of the business model canvas (BMC) in which companies most frequently implement artificial intelligence (AI) tools and to determine the structural and operational factors that determine this use. Specifically, the study aims to verify how company size, business profile (manufacturing/ services), technological sector type/other, and AI implementation advancement influence the likelihood of using AI in individual BMC components. Methodologically, the work consists of a literature review (SLR) and quantitative research. The work contributes to understanding the real-world digitalization of companies using AI by empirically verifying the research hypotheses using statistical tests and logit models. The research hypotheses are presented below.

H1s was tested using statistical tests of proportions. Hypothesis H1e, in turn, is an overarching hypothesis consisting of four specific sub-hypotheses:

- Hypothesis H1s: "The percentage of companies using AI tools is significantly higher than the percentage of companies not using AI in most of the nine areas of the Business Model Canvas".
- Main Hypothesis (H1e): The likelihood of implementing AI in individual business model canvas (BMC) areas is determined by the structural characteristics of the company (size, industry, technological profile) and the overall intensity of AI use within the organization, with patterns of these relationships showing stability in 2024-2025.
- Specific Hypothesis 1 (H1e-a): The primary and universal determinant of AI implementation in any BMC area is the overall intensity of the organization's digitalization; the more BMC components already use AI, the higher the likelihood of its implementation in the next area (path effect and digital synergy).

- Specific Hypothesis 2 (H1e-b): The impact of overall digitalization intensity on decisions to implement AI in the business model is dependent on enterprise size, revealing statistically significant patterns in selected BMC areas for small and large companies.
- Specific Hypothesis 3 (H1e-c): A company's affiliation with the information technology (IT) sector is a significant structural feature that co-determines (together with digitalization intensity) the likelihood of implementing AI in selected, specific BMC components.
- Specific Hypothesis 4 (H1e-d): A company's affiliation with a service or manufacturing profile is a significant structural feature that co-determines (together with digitalization intensity) the likelihood of implementing AI in selected, specific BMC components.

This work is consistent with the current research on the application of AI tools in enterprise business areas. From a scientific perspective, the work is significant because it demonstrates that the BMC template is no longer merely a descriptive or conceptual tool, but rather a tool that can be applied mathematically. This allows for the presentation of not only a static perspective on BMC (statistical tests) but also a dynamic one (logit models). This allows for replication of the study in other countries and industries. In terms of the theory of innovation diffusion, the work demonstrates a feedback loop, for example, that the level of AI implementation in BMC, as X, increases the likelihood of AI implementation in a specific area Y. The study also allows for the development of new theories at the interface of management and IT, for example, management goals, financial indicators, and other aspects of technology configuration options, change management, understanding business needs and technology capabilities at the interface between management and those responsible for the technical implementation of digital technologies, employee competencies and AI technologies, and reducing the stress resulting from digital transformation as part of the implementation of AI tools in specific positions.

2. Methods

Two research methods were used in the study. The first focused on a systematic literature review. The second quantitative method enabled empirical research based on a developed survey (Creswell, Creswell, 2022; Fisher, 2017).

The systematic literature review aimed to collect scientific articles that showed the applications of AI in the elements of the BMC template. The systematic literature review was conducted by defining relevant keywords or combinations thereof for the purposes of advanced searching in scientific literature databases. Next, the results obtained were used to identify relevant articles for each element of the research area concerning the application of AI tools.

Subsequently, the selected articles were analysed to develop a matrix of AI applications in individual BMC elements. The diagram below shows the successive stages. The result of the systematic literature review is the identification of research gaps, information on the research methods used to date, the possibility of developing new directions for future research, new research questions, as well as information relevant to businesses with practical implications for the use of AI tools in management. The diagram below shows the systematic literature review.

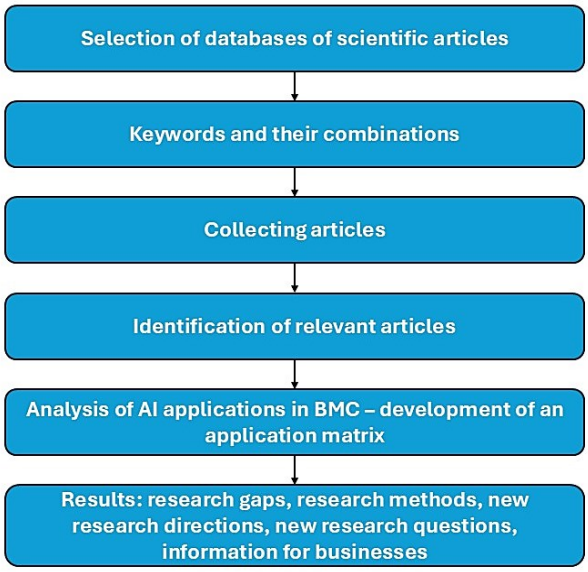


Figure 1. Schematic diagram of the systematic literature review conducted.

Source: Authors own work.

Operationally, the study consisted of the following stages. First, scientific literature databases were selected. The Mendeley and Google Scholar databases were selected for the study. Next, keywords and their combinations were selected. The keywords were based on words such as: Business Model Canvas, BMC, Canvas, value propositions, customer segments, channels, customer relationship, revenue, key resources, key activities, key partnerships, cost structure, AI, artificial intelligence, artificial intelligence tool, artificial intelligence tools. These words made it possible to build combinations of words for advanced searches, e.g.: AI and value propositions; artificial intelligence tool and customer segments, etc. Based on these combinations, the next step was to select relevant articles based on their relevance to the keywords and the research area. Next, the usefulness of the articles was identified in relation to the research objective. The next stage was to build a matrix indicating specific applications of AI in specific BMC elements based on the indications in the identified scientific articles. On this basis, the results were compiled and presented in the form of graphs. In the final step, as part of the discussion of the research results, conclusions were presented regarding research gaps, further research, the methods used, and the results in relation to the research objective. The results of the literature review are intended to answer the research questions.

The quantitative research method aimed to empirically determine whether the companies covered by the study use AI solutions in individual elements of the BMC or not. The essence of this method is to explain reality based on data that represent the actual state of affairs. In this respect, the quantitative research method allows us to learn about the actual cognitive results, enabling us to draw specific conclusions and interpretations that may serve as a basis for further in-depth research. The basic issue in the quantitative research method is the choice of data collection tool. As part of the study, a questionnaire survey was chosen, in which it was decided to develop closed YES/NO questions. The basis for choosing this type of questions were advantages such as: ease of answering by the respondent resulting from the clarity and unambiguity of the questions, relatively short time needed to complete the survey, and ease of statistical analysis in quantitative research. Another advantage of using closed YES/NO questions is the ability to observe changes indicating the level of AI tool adoption among enterprises. The disadvantage of such a survey is the shallow level of opinion expression, which does not allow for in-depth examination of various issues and nuances related to the use of AI. However, in the broader context of the research strategy, the use of a survey questionnaire is consistent with the logic of the classical research process, in which data is first collected, examined at a general level, and conclusions are drawn that form the basis for separate detailed studies. This process is a deductive approach that is used in many areas of scientific research, including social and marketing research. It also responds to the need to prove a research hypothesis. This process also allows for faster identification of specific areas within a given research field that require in-depth study, e.g. for hypotheses in individual elements of the BMC.

Secondly, to identify the determinants of AI implementation in a given BMC area, 18 logistic regressions (logit models) were estimated – 9 models each for 2024 and 2025. A separate model for each BMC area was used as the dependent variable $Y \in \{0,1\}$. The following explanatory variables (X) were adopted: enterprise size (dichotomous variables for small, medium, and large companies; for micro companies, the intercept serves as the reference base), business sector (manufacturing or services), technological profile (technology company or other; IT industry or other), and digitization intensity (a discrete variable 0-8, denoting the number of other BMC areas with AI tools implemented, which allowed for avoiding multicollinearity). It is also worth emphasizing the advantages of the logit model, e.g., implementing AI in a given BMC area is a binary decision – the company either implemented the technology (1) or did not (0). The choice of the logit model in the study also stemmed from its ability to precisely analyze dichotomous variables and synergy effects, which enabled interpretation of the results using odds ratios (ORs). This tool, unlike linear regression, ensured business realism by limiting predictions to a range of 0-1 and allowed for rigorous assessment of model quality. Determining the effects of a given model through probability of the logit model is also crucial. For example, with use of the logit model ideally indicates a breakthrough moment. When a company implements AI in approximately 4-5 other

BMC areas, the probability of success in the studied area exceeds the 0.5 threshold (50%). That the process is non-linear. It also illustrates changes, for example: at the beginning (values 0-2), the probability increase is slow. Between 3 and 6, a sharp increase (an explosion of adoption) occurs, and above 8, saturation occurs. Thanks to the logit model is possible to recived the graph transforms an abstract mathematical algorithm (the logarithm of the odds ratio) into an intuitive roadmap. This allows for immediate understanding of the logical chain of cause and effect: the greater the digital maturity of the entire company, the lower the risk and the greater the ease of implementing AI in a new segment. This approach allows for the identification of technology adoption phases into practical stages. Below is a diagram showing the successive stages of quantitative research.

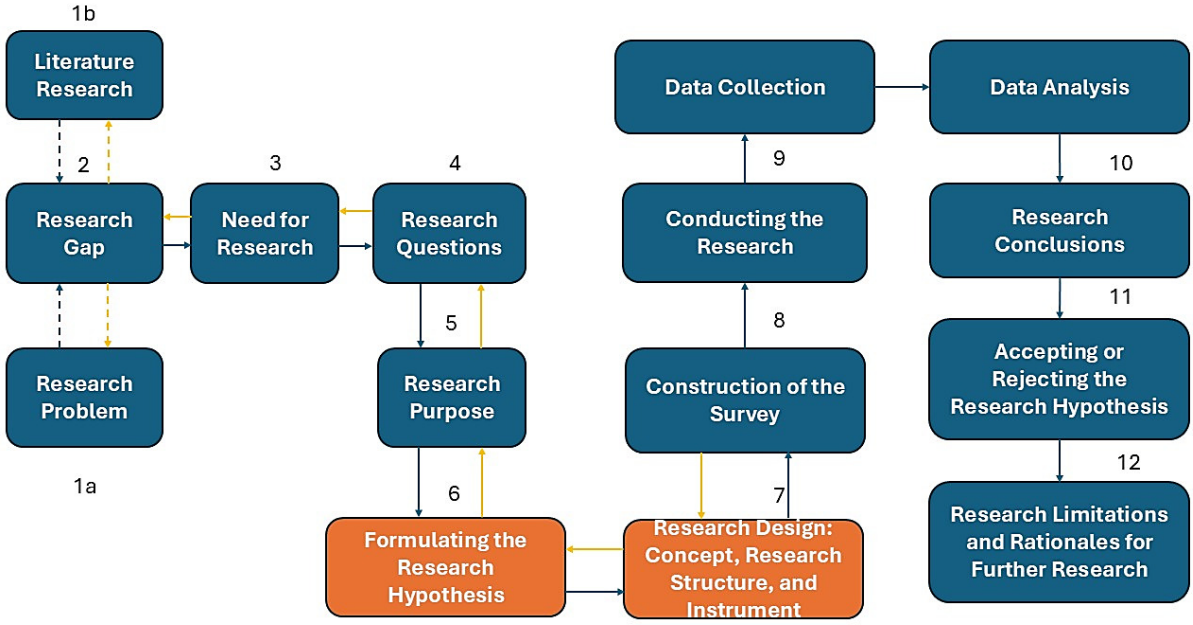


Figure 2. Diagram showing the steps involved in conducting a quantitative study.

Source: Authors own work.

The quantitative research began with stage 1, which was divided into sub-stages 1a and 1b. In sub-stage 1a, theoretical considerations were made regarding the use of AI tools in the enterprise. This stage involved a systemic analysis of the enterprise, its information space and AI tools. A systemic comparison of the enterprise, the information system and AI as a system allowed for the identification of dependencies, relationships and areas that require research, i.e. the need to apply a universal template in the form of BMC. In turn, in sub-stage 1b, literature research was carried out to search for information on completed studies on the application of AI tools in individual elements of BMC. Sub-stages 1a and 1b identified a research gap in stage 2, which indicates that the phenomenon of the application of AI tools in individual areas of business models has not been sufficiently researched. Stage 3 summarises the processes from the sub-stages in the form of the need to conduct research. Formulating the research need in stage 3 leads to research questions in stage 4, such as: In which elements of the business model

do the companies under study use AI tools? In which of these elements are AI applications most numerous? What impact do variables (enterprise size, industry, technological profile) and the overall intensity of AI use in the organization have on the implementation of AI tools in individual areas of the BMC? In turn, in stage 5, the research objective is formulated: to identify the applications of artificial intelligence tools in individual areas of the Business Model Canvas. In stage 6, research hypotheses are formulated: H1s, H1e, H1e-a, H1e-b, H1e-c, H1e-d. This leads to work on the research models in stage 7, specifically on the research concept, its structure and the selection of research tools. This is a very important point, where it was decided that, within the adopted research area, a research questionnaire consisting of nine research questions (stage 8) concerning the use of AI tools in each of the BMC elements would be developed. The following closed YES/NO questions were developed:

Does your organisation use Artificial Intelligence solutions for customer segmentation?

1. Does your organisation use Artificial Intelligence solutions to create value propositions for customers?
2. Does your organisation use Artificial Intelligence to optimise distribution channels?
3. Does your organisation use Artificial Intelligence to build relationships with customers?
4. Does your organisation use Artificial Intelligence solutions to manage key assets?
5. Are key activities in your organisation supported by Artificial Intelligence solutions?
6. Does your organisation use Artificial Intelligence solutions to collaborate with key partners?
7. Is Artificial Intelligence used in your organisation to optimise the revenue structure?
8. Is Artificial Intelligence used in your organisation to optimise the cost structure?

In addition to the above questions, the surveyed entities were asked to indicate the size of their organisation and location data.

It is also worth noting that, including stage 8, we allowed for the possibility of adjusting individual stages, which gave us flexibility in terms of possible changes. Data collection began in stage 9. The data was collected electronically during registration for remote broker meetings and workshops on the applications of artificial intelligence in business and everyday life AI ABEL AI Applications in Business and Everyday Life (Virtual edition) in 2024 and 2025. Data was collected from 15 March 2024 to 12 June 2024 and from 14 March 2025 to 12 June 2025 during registration (Digital Economy Lab 2024; Digital Economy Lab 2025). During the study, we also took into account the participation of entities other than companies, i.e. foundations, associations, scientific research and development institutes, and universities, but we limited the results of the study to companies only, in accordance with the research objective and research hypothesis. In total, data was collected from 358 entities during the registration process for the *AI ABEL (AI Applications in Business and Everyday Life)* event in 2024, and from 276 entities in 2025. The sample included companies, universities, research and development institutes, foundations and associations. In accordance with the purpose of the

study, the analysis was limited to enterprises only. As a result of the data cleaning process, in which entities that did not meet the criteria were rejected, the final sample included 200 enterprises in 2024 and 155 enterprises in 2025, respectively. It should be emphasised that participation in the study required consent to the processing of data for scientific purposes. In 2024, 269 entities (74.9%) gave their consent, while 89 entities (24.9%) did not. In 2025, the corresponding figures were 220 entities (79.7%) and 56 entities (20.3%). Only those observations for which consent to use the research data was obtained were included in further analyses. Share of individual companies by size in 2024: micro: 45%; small: 36%; medium: 12%; large: 8%. Share of individual companies by size in 2024: micro: 42%; small: 35%; medium: 14%; large: 9%.

3. Methods

Two research methods were used in the study. The first focused on a systematic literature review. The second quantitative method enabled empirical research based on a developed survey (Creswell, Creswell, 2022, Fisher, 2017).

3.1. Literature research results

The identification of relevant articles published between 2021 and 2025 allowed us to select 100 articles, which were subjected to an in-depth analysis in terms of research methods and areas of application of AI tools within the Business Model Canvas. A detailed list of sources is presented in the Bibliography section: [3], [6-13], [16-17], [25-26], [28-30], [32-33], [36], [38-39], [41-45], [47-50], [52-56], [58-60], [62], [64-73], [75], [77-79], [84-88], [91-92], [97], [99-102], [104], [106-111], [113], [115-121], [123-125], [129], [132-134], [136-140], [143-148].

First, an analysis of the research methods used was carried out. The chart below shows the percentage share of methods used.

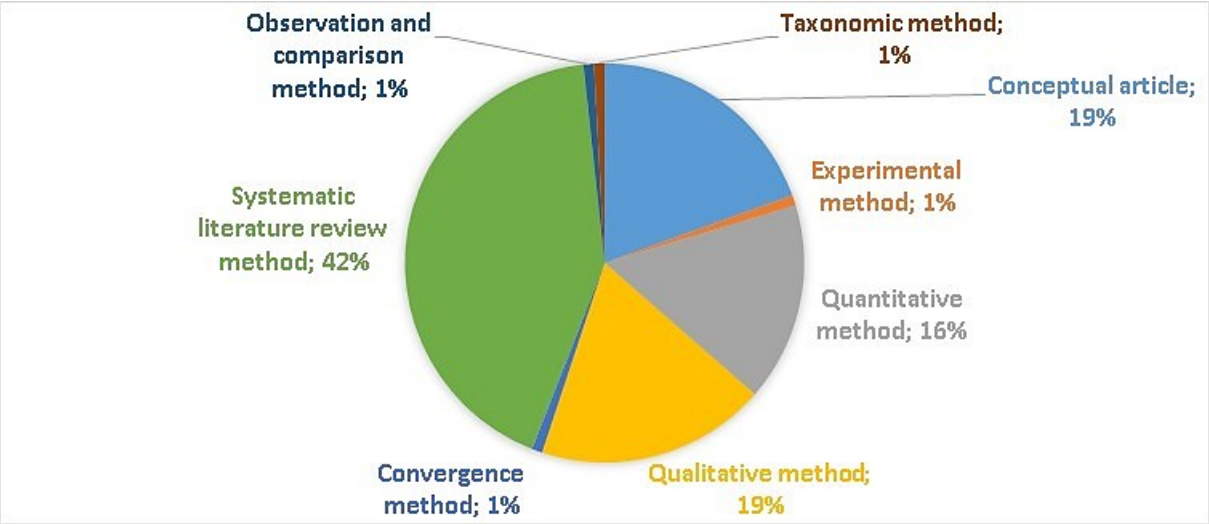


Figure 3. Percentage share of research methods used in the application of AI tools.

Source: Authors own work.

The results of the study indicate that the most commonly used research method is systematic literature review, with a share of 42%. The next most common method is the qualitative method, with a share of 19%. Conceptual articles have the same percentage share. The percentage share of the quantitative method is 16%. The percentage share of tools within the qualitative and quantitative methods was also analysed. In the qualitative method, interviews account for 50% and case studies for the other 50%. In the quantitative method, classical statistics tools account for 47%, machine learning and deep learning tools account for 37%, and econometric tools account for 16%.

The number of individual AI technologies used was also examined. The chart below presents the number of technologies used.

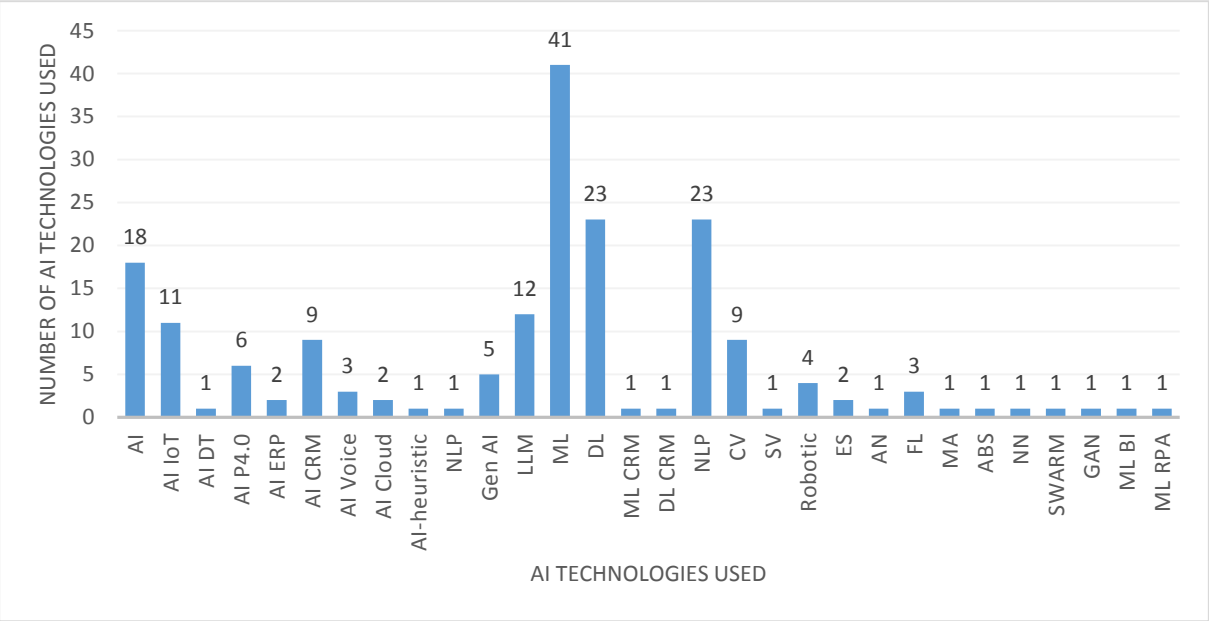


Figure 4. Number of individual AI tools used.

Source: Authors own work.

The results of the study indicate that among the most prominent technologies are Machine Learning (ML) – 41, followed by Deep Learning (DL) – 23, Natural Language Processing (NLP) – 23. The chart also shows the number of technologies used that fall under the generalised acronym AI (Artificial Intelligence) – 18 (the literature review included articles that used the term AI without specifying what it meant). Within the adopted definition and taxonomy, the article classified the Internet of Things (IoT) as part of this group of AI ML and DL algorithms, but it was decided to present this group separately due to the inability to divide it. Among other notable technologies, it is also worth mentioning Large Language Models (LLM) – 12. Others worth noting are AI IoT (Artificial Intelligence Internet of Things) – 11, Computer Vision (CV) – 9, AI CRM (Artificial Intelligence Customer Relationship Management) – 9, AI P.4.0 (Artificial Intelligence Industry 4.0) – 6.

It is worth noting that it is possible to sum up selected technologies that are part of the so-called Industry 4.0. Then the number will increase to as many as 25, assuming that only the following components are included: AI P.4.0, AI IoT, Robotic, AI Digital Twin (DT), AI Cloud, Artificial Intelligence Robotic Process Automation (AI RPA). However, this is problematic due to other components that can also be included in this category. This synthetic approach aims to indicate that some of the components may be of significant importance from the point of view of the Industry 4.0 concept, in particular their application in the optimisation of production processes.

To obtain a more accurate picture based on the SLR, the identified AI technologies were assigned to their main functional roles in the Business Model Framework (BMC). For example, Machine Learning (ML) and Deep Learning (DL) technologies most often support the Key Activities component through process optimization and operational forecasting. Natural Language Processing (NLP) and Large Language Models (LLM) algorithms are primarily implemented in the Customer Relationships and Channels areas, automating communication and personalizing user experiences. Computer Vision (CV) technologies dominate the Key Resources area, responsible for automated quality control in production processes. Within the adopted taxonomy, the Internet of Things (IoT) is not treated as a standalone AI algorithm, but as a critical sensory infrastructure that generates data (data layer), which in the analyzed studies operates in close synergy with ML and DL algorithms (creating the so-called AI IoT – Artificial Intelligence Internet of Things). The creation of the AI IoT category (n = 11) highlights a significant taxonomic dichotomy. While the traditional Internet of Things (IoT) operates solely as an infrastructural connectivity layer for data collection, its convergence integrates edge computing. In the BMC framework, this elevates AI IoT from a mere technological infrastructure to a key enabler of Key Partners (KP) Key Resources (KR) Key Processes, and other effectively combining the digital data stream with algorithms. This is especially important because edge computing can be a crucial implementation element in smaller or medium-sized manufacturing enterprises. The presence of the general "AI" item in the chart reflects publications describing the implementation of integrated, multifunctional

IT systems with a holistic approach. In these cases, companies implemented off-the-shelf commercial platforms (e.g., intelligent enterprise management systems) in which AI operates as a unified system (black box), preventing authors from isolating individual algorithmic techniques.

Table 1.
Functional map of dominant AI technologies in BMC areas based on the conducted SLR

AI Technology (Frequency in Fig. 4)	**Main Functional Role in Business**	**Target BMC Areas (Osterwalder)**	**Example Enterprise Application**
General AI (n = 18)	Unspecified black-box automation and general cognitive computing support, focusing on turnkey commercial software integration, automated administrative workflows, native platform data grouping, and standardized smart asset bundling.	• Key Activities (KA) • Customer Relationships (CR) • Customer Segmentation (CS) • Cost Structure (CS) • Channels (CH • Key Partners (KP) • Value Proposition (VP)	Out-of-the-box commercial software integration, automated office workflows, and basic cognitive assistance, built-in Suite automation to automate routine scheduling, email drafting, and meeting summarization; out-of-the-box web analytics grouping, standard smart hardware bundles.
Machine Learning (ML) (n = 41)	Predictive analytics, anomaly detection, automation of structural decisions.	• Cost Structure (CS) • Key Activities (KA) • Revenue Streams (RS)	Dynamic pricing, market demand forecasting, logistics cost optimization, energy consumption optimization, back-office process Automation, supplier selection.
Deep Learning (DL) (n = 23)	Advanced pattern recognition, multi-dimensional and unstructured data analysis.	• Key Activities (KA) • Key Resources (KR)	Predictive maintenance, predictive asset lifecycle management, automated machine vision quality control on production lines, intelligent property and infrastructure Digital Twins.
Natural Language Processing (NLP) (n = 23)	Processing, analysis, and structuring of text data and human speech.	• Customer Relationships • (CR) Channels (CH)	Customer feedback clustering, social media sentiment analysis, automated complaint categorization, real-time customer sentiment tracking, multilingual content localization.
Large Language Models (LLM) (n = 12)	Content generation, advanced conversational interaction, real-time knowledge synthesis	• Value Proposition (VP) • Customer Relationships (CR)	AI-driven advisory systems, hyper-personalization of product offers, 24/7 generative technical support.

Cont. table 1.

AI IoT (n = 11)	Integration of digital intelligence with physical infrastructure (sensing + edge computing	• Key Resources (KR) • Key Partners (KP) • Key Activities (KA)	Autonomous supply chain management (tracking and telemetry), smart warehousing, sensor-based monitoring of resource consumption and processes, edge-powered cyber-physical assets, predictive maintenance-as-a-service, closed-loop autonomous process control, automated energy and emission load balancing.

Source: Authors own work.

The presented functional map illustrates a clear division between specialized AI technologies (such as NLP or DL) and holistic or infrastructure-based solutions (General AI, AI IoT). This classification demonstrates that while selected algorithms are responsible for the point-by-point optimization of operational processes or customer relationships, integrated and edge systems are cross-cutting factors enabling the transformation of multiple areas of the BMC template simultaneously.

The study identified areas of application for AI tools in specific parts of the Business Model Canvas.

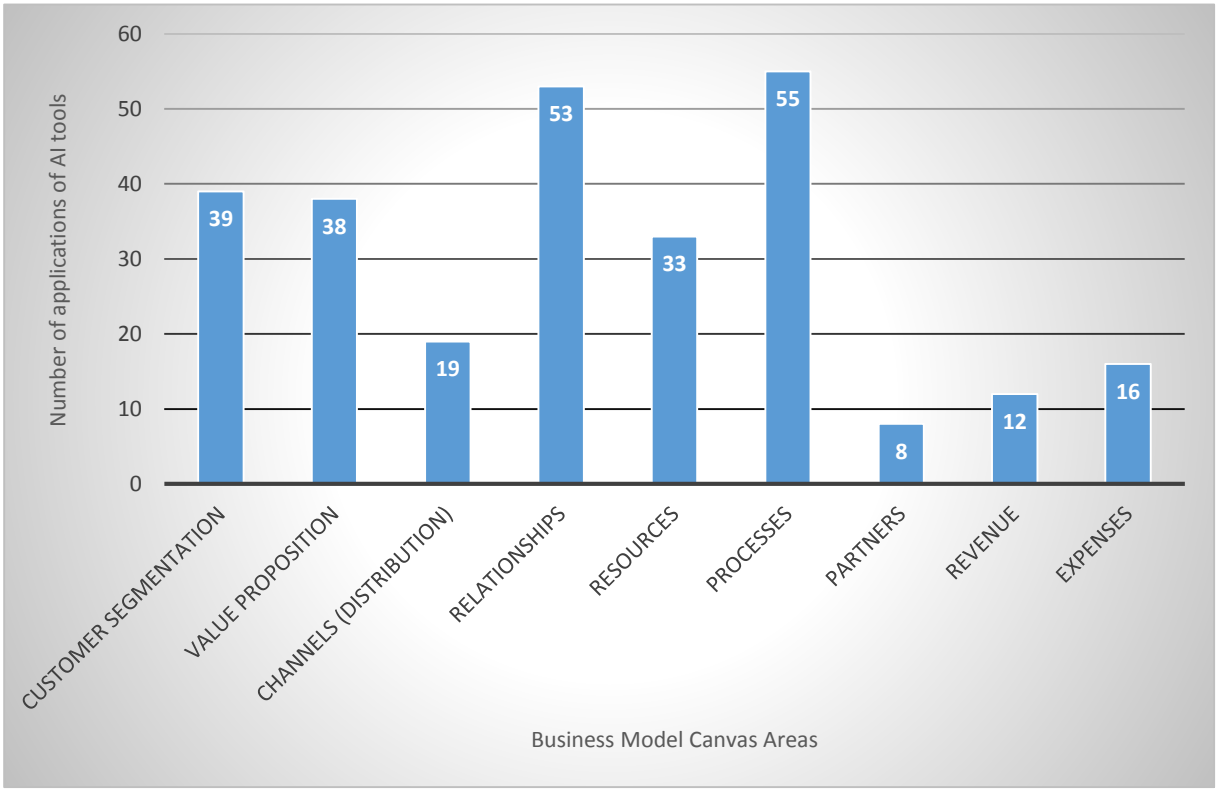


Figure 5. Number of applications of AI tools in specific areas of the BMC.

Source: Authors own work.

The results of the study indicate that the largest number of applications of AI tools occurs in the area of so-called key activities – 55. This is followed by customer relations – 53. Next in line are customer segmentation – 39, value proposition – 38, and key resources – 33.

3.2. Survey results – statistic tests

The data collected in the survey enabled quantitative analysis through graphical presentation of the responses obtained from companies and testing of statistical hypotheses. The survey, on the other hand, aimed to obtain answers from the companies themselves regarding the application of AI tools in specific areas of BMC. The answers to closed YES/NO questions made it possible to obtain graphs of the use or non-use of AI tools in a given BMC area by the companies surveyed during brokerage meetings and workshops in 2024 and then in 2025 (Digital Economy Lab 2024; Digital Economy Lab 2025).

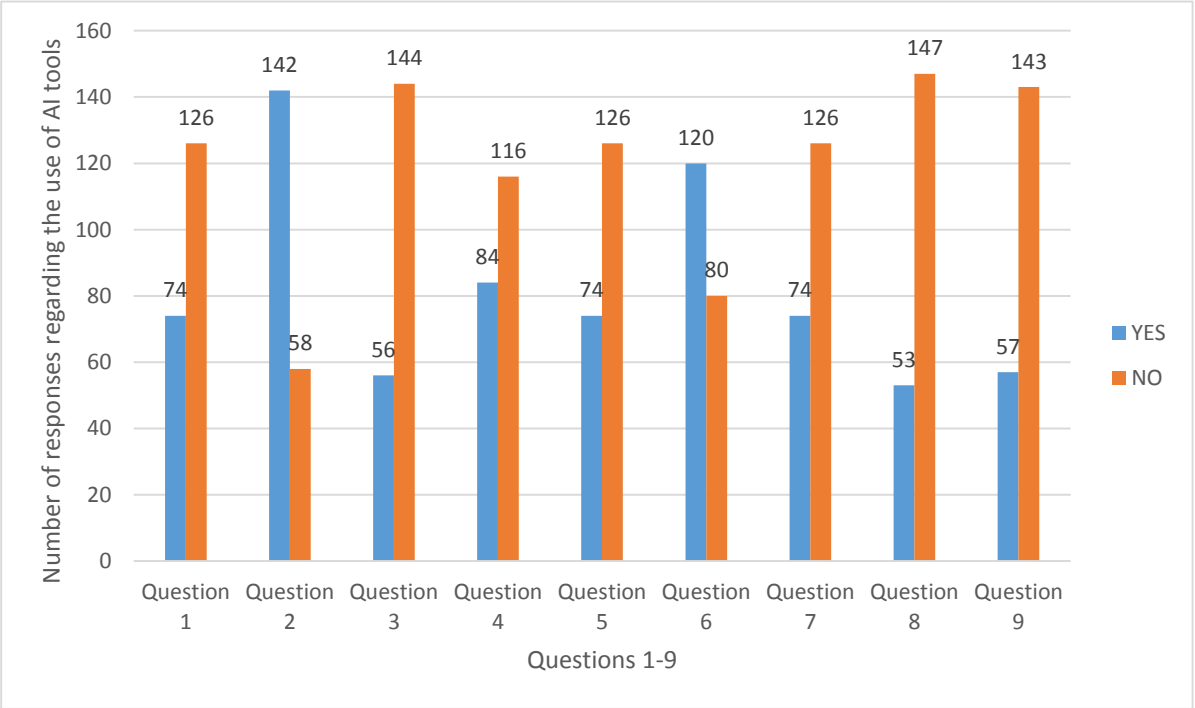


Figure 6. Responses obtained in the survey. YES/NO questions concerning the declaration of the use or non-use of AI tools by the surveyed companies in a given BMC area in 2024.

Source: Authors own work.

The survey results indicate that in most cases, companies declare that they do not use AI tools in specific BMC areas. Figure 6 shows that these areas include: question 1 – customer segmentation (126 responses), question 3 – distribution channels (144 responses), question 4 – customer relationships (116 responses), question 5 – key assets (126 responses), question 7 – partner relationships (126 responses), question 8 – revenue structure (147 responses), question 9 – cost structure (143 responses). The cases in which the use of AI in individual BMC areas was most frequently reported were: question 2 – customer value proposition (142 responses), question 6 – key activities (120 responses) (Digital Economy Lab 2024;).

The results were checked using the unit proportion test, also known as the Z-test, and the Chi-square test, which assumes that the proportion in a given population has a specific value. In this case, it is 50%. This allows us to test the null hypothesis H_0 and the alternative hypothesis H_1 in a given BMC area. The following set of hypotheses was proposed: H_0: Hypothesis of an equal 50/50 distribution. This means that YES or NO responses do not differ statistically. H_1: No equal 50/50 distribution. This means that YES or NO responses predominate. The table below presents the results of the proportion test for individual BMC components regarding declarations of artificial intelligence applications in the surveyed enterprises in 2024 (Creswell, J.W., Creswell, D.C. 2022; Fisher, 2017).

Table 2.
Unit proportion test Z and Chi-square test of individual BMC components concerning declarations of AI tools applications in the surveyed companies in 2024

No.	BMC Component	YES	NO	Z-statistic	$\chi 2$ statistic	p-level	Test result α=0.05	Advantage
1	Segmentation	74	126	3,68	13,52	<0,05	Statistically significant difference: Rejection of H0	Advantage NO
2	Value Proposition	142	58	5,94	35,28	<0,05	Statistically significant difference: Rejection of H0	Advantage YES
3	Distribution Channels	56	144	6,22	38,72	<0,05	Statistically significant difference: Rejection of H0	Advantage NO
4	Customer Relationships	84	116	2,26	5,12	<0,05	Statistically significant difference: Rejection of H0	Advantage NO
5	Key Assets	74	126	3,68	13,52	<0,05	Statistically significant difference: Rejection of H0	Advantage NO
6	Processes	120	80	2,83	8	<0,05	Statistically significant difference: Rejection of H0	Advantage YES
7	Partner Relationships	74	126	3,68	13,52	<0,05	Statistically significant difference: Rejection of H0	Advantage NO
8	Revenues	53	147	6,65	44,18	<0,05	Statistically significant difference: Rejection of H0	Advantage NO
9	Costs	57	143	6,08	36,98	<0,05	Statistically significant difference: Rejection of H0	Advantage NO

Source: Authors own work.

The results of the proportion tests clearly indicate that statistically significant differences ($p < 0.05$) exist in all nine areas of the BMC template, which allowed us to reject the null hypothesis of an equal distribution of responses. A clear predominance of "YES" responses (Advantage YES) was observed only in the Value Proposition and Processes areas, proving that AI tool implementation in 2024 was strongly focused on generating new value for customers and operational optimization. The remaining seven business model components are dominated by a lack of implementation (Advantage NO), indicating the still untapped potential of AI tools.

The empirical distribution of “YES” and “NO” responses provided in the analysis of nine areas of the Business Model Canvas (BMC) template is presented in Figure X. The visualized data illustrate the structure of declarations regarding the implementation of artificial intelligence tools, constituting a direct starting point for the proportion tests and chi-square analysis.

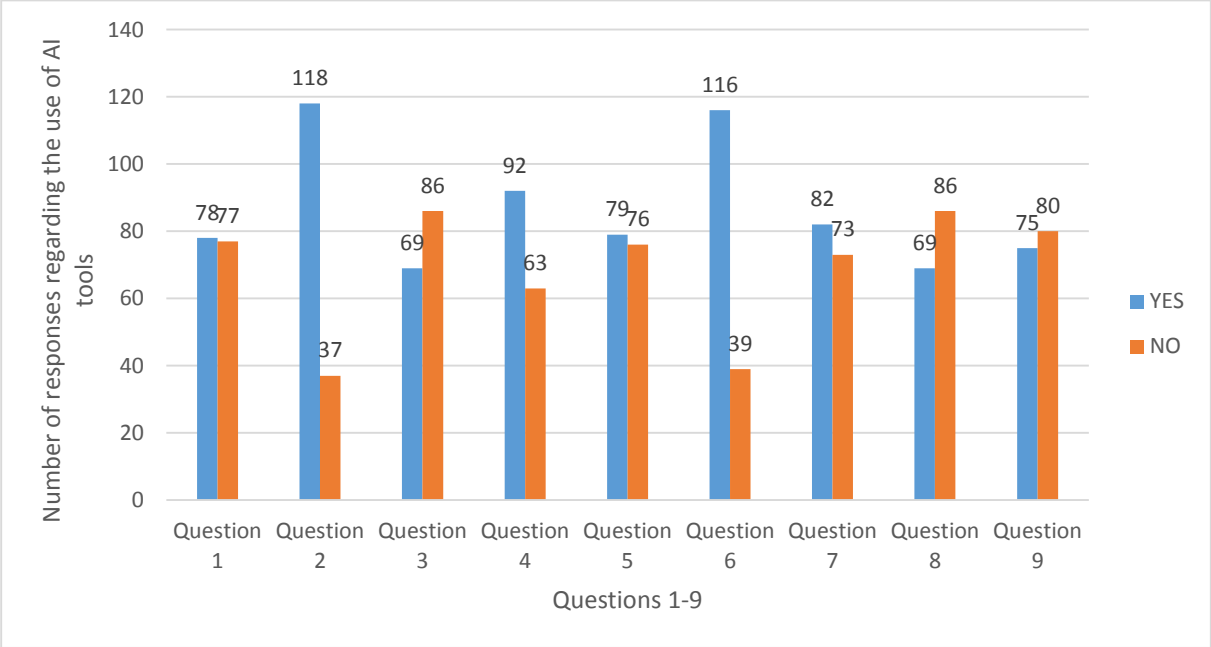


Figure 8. Responses obtained in the survey. YES/NO questions concerning the declaration of the use or non-use of AI technology by the surveyed companies in a given BMC area in 2025.

Source: Authors own work.

The survey results indicate that in most cases, companies declare the use of AI tools in specific BMC areas. Figure 8 shows that these areas include: question 1 – customer segmentation (78 responses), question 2 – value proposition (118 responses), question 4 – customer relationships (92 responses), question 5 – key assets (79 responses), question 6 – processes (116 responses), question 7 – partner relationships (82 responses). The cases in which the majority of respondents stated that AI tools were not used in particular BMC areas were: question 3 – distribution channels (86 responses), question 8 – cost structure (86 responses), question 9 – revenue structure (80 responses).

As in 2024, the results for individual BMC areas were tested using a unit proportion test and Chi-square for 2025 (Creswell, J.W., Creswell, D.C., 2022; Fisher, 2017).

Table 3.
Unit proportion test Z and Chi-square test of individual BMC components concerning declarations of AI tools applications in the surveyed companies in 2025

No.	BMC Component	YES	NO	Z-statistic	$\chi 2$ statistic	p-level	Test result α=0.05	Advantage
1	Segmentation	78	77	0,08	0,006	>0,05	There is no basis to reject H0	No advantage (50/50)
2	Value Proposition	118	37	6,506	42,329	<0,05	Statistically significant difference: Rejection of H0	Advantage YES
3	Distribution Channels	69	86	1.365	1,865	>0,05	There is no basis to reject H0	No advantage (50/50)
4	Customer Relationships	92	63	2,329	5,426	<0,05	Statistically significant difference: Rejection of H0	Advantage YES
5	Key Assets	79	76	0,241	0,058	>0,05	There is no basis to reject H0	No advantage (50/50)
6	Processes	116	39	6,185	38,252	<0,05	Statistically significant difference: Rejection of H0	Advantage YES
7	Partner Relationships	82	73	0,723	0,523	>0,05	There is no basis to reject H0	No advantage (50/50)
8	Revenues	69	86	1,365	1,865	>0,05	There is no basis to reject H0	No advantage (50/50)
9	Costs	75	80	0,402	0,161	>0,05	There is no basis to reject H0	No advantage (50/50)

Source: Authors own work.

The results of the proportion tests show statistically significant differences ($p < 0.05$) in three areas of the BMC template – Value Proposition, Processes, and Customer Relationships – where a clear predominance of "YES" responses was noted, confirming the focus of AI implementations on value creation, process optimization, and relationship building. In the remaining six components of the business model, there is no basis for rejecting the null hypothesis ($p > 0.05$), which indicates a relatively balanced distribution of responses (50/50). This data pattern indicates that the diffusion of AI technology in these areas is still transitional and has not yet achieved a dominant market position.

The study, using tests, identified which individual BMC areas had significant results regarding the use or non-use of AI tools, or the lack of a significant advantage. In 2024, most companies used AI tools in areas such as value proposition and processes within core activities. In other areas, such as market segmentation, customer relationships, channels, key partners, key resources, revenues, and costs, the majority of responses were "no". These results indicate that in 2024, the working hypothesis H1s is not met for most areas. Therefore, there were more areas within the BMC where a larger percentage of companies did not achieve an advantage in using AI tools. However, it is worth noting the two aforementioned areas where

the percentage of companies using AI tools is higher. In the first case, these are processes within core activities, which also stand out significantly in the systematic literature review. This result indicates that companies are exploring the use of AI tools in processes to increase their effectiveness at both the operational and strategic levels. AI tools can be used in processes in areas such as production. However, they can also be applied more broadly, for example, within the framework of Industry 4.0, for example, they can be used for process optimization within horizontal and vertical integration. They can be used to optimize processes using specific raw materials. Furthermore, criteria regarding energy consumption and pollutant emissions can be included within the same optimization framework. Another important issue for the application of AI tools from a process perspective is the product lifecycle. AI tools contribute to the optimization of processes related to product lifecycle management, from the purely development level to extending the product lifecycle as part of entering markets where the product has not yet appeared. It is also worth noting that the use of AI tools in the product lifecycle area applies not only to processes but also to the creation of value propositions. It is therefore not surprising that most companies are seeking AI tool applications to create value propositions such as specific functionalities, features, price, performance, reliability, etc. It is worth emphasizing that this is also an area that stands out significantly in a systematic literature review. It's also worth noting that areas like customer relationships and market segmentation also stood out in the systematic literature review. However, the results of the 2024 study indicate that most companies have not yet leveraged AI tools in these areas.

In 2025, a similar study was conducted using the same questionnaire. The quantitative analysis was based on the same working hypothesis and statistical hypotheses. However, the study results revealed a completely new picture regarding the application of AI tools in specific areas of BMC. Among the areas where the percentage of AI tool applications was significant were: processes within key activities, value propositions, and customer relationships. Therefore, for the second year in a row, areas such as processes and value propositions showed a higher percentage of applications. Therefore, it can be hypothesized that companies interested in AI tools are choosing to use them in processes and value propositions. The results of the 2025 study also point to a new, prominent area of AI application in BMC: customer relationships. The use of AI tools in this area applies to activities such as acquiring new customers, retaining existing customers, increasing sales, but also to forms of contact and opportunities for engaging customers in relationships, such as co-creation, problem-solving, building awareness of products or services, and tailoring offers to needs. It's worth emphasizing that the customer relationship area ranks second, right after processes, based on systematic literature reviews. The results of the 2025 study also point to an interesting phenomenon regarding the use or non-use of AI tools within companies. In six BMC areas: segmentation, channels, key resources, key partners, revenues, and costs, the significance test indicated statistical hypothesis H0, which indicated that H0: the hypothesis of an equal 50/50 distribution, meaning that YES or NO responses do not statistically differ. Analyzing the values in individual

areas, it can be seen that there are areas where the percentage of companies using and not using AI is very similar, for example, 78 companies answered YES and 77 NO. Other examples include key resources, where 79 answered YES and 76 answered NO, and channels, where 69 answered YES and 86 answered NO. The results indicate that, in addition to the three main areas of AI tool application mentioned above (processes, value proposition, relationships), YES responses indicating the use of AI tools also occur in areas such as segmentation, key resources, and partner relationships. This could suggest that AI tools are used in most areas of BMC. However, at a statistical level, the differences between the percentage of companies using AI tools and the percentage of companies not using them are similar. The same applies to three areas where the percentage of NO responses is clearly higher than YES, including distribution channels, revenues, and costs. Therefore, the current situation within the applied statistical test indicates that neither the main hypothesis H1s can be confirmed in 2025. The survey results indicate that within just one year (2024–2025), the structure of AI applications in the BMC model has changed. The two previously dominant areas, processes and value proposition, have been joined by customer relations, and in several other areas (segmentation, key resources, partnerships) similar proportions of AI use and non-use have been observed.

3.3. Survey results – logit models

As part of the quantitative study, logit models were estimated. A total of 18 logit models were estimated – one for each identified BMC area. The models were estimated based on data obtained through surveys conducted during brokerage meetings and workshops in 2024 and 2025 (Digital Economy Lab 2024; Digital Economy Lab 2025). Nine models were estimated for 2024 and nine for 2025. The aim of estimating these models was to examine the main determinants influencing decisions related to the implementation of AI tools in individual BMC areas. All estimated models are presented in Appendix 1 and Appendix 2. The initial structure of the logit models consisted of the following variables: X_1 – small company, X_2 – medium-sized company, X_3 – large company, X_4 – application of AI tools in other BMC areas, X_5 – service or manufacturing company, Variable X_5 – service or manufacturing company, Variable X_7 – IT or other company. The intercept serves as a reference base for micro-enterprises. The Yi variables represent the subsequent BMC areas: Y_1 – segmentation, Y_2 – value proposition, Y_3 – distribution channel, Y_4 – customer relationships, Y_5 – key resources, Y_6 – key activities, Y_7 – key partners, Y_8 – revenue structure, and Y_9 – cost structure.

The results of the study conducted using logit models for 2024 and 2025 indicated that the variable "AI tools used in other areas of BMC" was a significant factor in all 18 models in both 2024 and 2025. Therefore, it can be concluded that this is a universal variable. It can also be concluded that implementing AI in one area generates network benefits and facilitates the diffusion of AI tools to other areas of the enterprise's business model. Furthermore, the greater the number of areas in which AI tools are used, the greater the likelihood of using AI tools in another area of the business model. Therefore, the use of AI tools increases the likelihood of

adopting these technologies in subsequent areas. It can be concluded that a strong feedback effect occurs in the digitalization process – positive experiences with implementing AI tools in one area influence the decision to implement them in the next. A lack of positive experiences with AI can block or delay decisions regarding further implementations.

In 2024, in Model 5, the impact of company size was revealed only in the area of key resources (Model 5). The X_3 variable (large company) proved statistically significant. This result can be explained by the fact that large companies possess larger resources due to their organizational structure. Therefore, there are emerging needs for more effective resource management, and AI tools can meet these needs. It should also be emphasized that large companies have correspondingly large capital resources, for example, large companies can create their own data centers, purchase expensive licenses, or employ scarce specialists (e.g., data scientists). The model confirms this. The positive, very high coefficient for variable X_3 (2.0139; OR = 7.492) clearly demonstrates the existence of a high entry threshold. Developing modern resources—such as advanced data centers, proprietary algorithms, or teams of specialized data engineers—requires significant financial outlays. Large companies have the advantage of free capital, economies of scale, and an existing, mature IT infrastructure. Although being a large company drastically increases the chances of resource transformation (by nearly 650%), this model reveals strong support from the X_4 variable (AI Application; OR = 2.172). This means that large entities not only passively possess resources but also digitize them. Artificial intelligence acts as a "catalyst", enabling more effective management and monetization of resources available only to large organizations (e.g., gigantic data sets – Big Data). For example, previously implemented algorithms become a knowledge base that optimizes resource management, which is crucial in a large company with a significant amount of resources – learning curve effects appear faster. It is also worth noting that resources in the context of BMC include both human resources and assets such as machines, devices, and equipment, which are crucial for process execution. Therefore, resources can be used to optimize a significant portion of processes, including other areas of BMC through processes. It's also worth examining this result from the perspective of the resource-based view (RBV) (Wernerfelt, 1984), a concept from the field of strategic management that suggests that the sources of sustainable competitive advantage are based on a company's internal resources and competencies, not on market structure. Following the assumptions of the resource-based view, it can be concluded that advanced digital technologies and AI are becoming a key, rare, and difficult-to-copy resource that builds sustainable competitive advantage—provided that these solutions are tailored specifically to the company's needs, often based on company-sourced data. It's also worth noting that competencies play a significant role in the resource-based view. Algorithms and data are valuable, but they can also be difficult to replicate—for example, because they feed unique data from internal company sources. However, these are "resources", or more precisely, AI resources. For these resources to create a competitive advantage, they require appropriate human resource competencies related to the use of AI tools,

such as: instruction design (Prompt Engineering), critical thinking, verification and evaluation, analytical and process thinking, the ability to combine data, interpret data, interpret results, digital empathy, task management (which tasks can be performed by AI), organizing work with AI (the process of planning, structuring, and coordinating tasks and AI resources with the daily responsibilities of an employee or team to automate tasks, accelerate processes, and increase efficiency), building workflow automation, digitizing analog resources, and so on. Small and medium-sized companies (X_1, X_2), due to budget constraints, are statistically much less likely to independently create such defined, modern key resources. Another solution may lie in publicly available AI tools. Advanced models (e.g., from OpenAI, Anthropic, or Google) are publicly available to anyone for a few dollars a month. This creates a certain paradox for RBV. Such AI tools are a common (not scarce) resource and easy to copy. They are a different "resource" than dedicated AI tools. According to RBV, they cannot, therefore, provide a competitive advantage on their own. However, what will continue to determine the use of AI resources is an employee with high universal AI skills, who becomes many times more effective than an employee without these skills. Another important issue from the point of view of RBV is the process of knowledge conversion known within the classic SECI model (Socialization, Externalization, Combination, Internalization) (Nonaka I, Takeuchi H. 1995) or newer versions of GenAI SECI (Uchihira, 2026). Digital organizational culture is also important. Digital Organizational Culture – DOC is a set of shared values, beliefs, norms and everyday behaviors of employees that define the way in which an organization uses digital technologies and tools to create business value (Teguh, Noermijati, Moko et al., 2022) as well as digital innovations as the creation (and resulting changes) of market offers, business processes or business models that result from the use of digital technologies (Nambisan, Lyytinen, Majchrzak, Song, 2022) or more specifically, digital innovations that are transforming the way products and services are developed, produced, and used. For example, innovations using digital technologies enable the "sharing" of resources such as cars, utilities, and accommodation. Such innovations are revolutionizing traditional markets, including media and entertainment, car rental and sales, hospitality, and even temporary labor markets (Bogers, Garud, Thomas et al., 2021).

It's also worth noting model number 2 in 2024, where a company operating in the IT sector significantly increases the chances of developing its value proposition. IT companies possess unique technological competencies that allow them to continuously and dynamically redefine their offerings. In their case, modifying their value proposition is not merely a response to market changes, but a natural element of their product strategy. The combination of artificial intelligence implementation (X_4) and the specific nature of the IT industry (X_7) creates a synergy effect. IT companies have a ready-made infrastructure and know-how, thanks to which implementing AI solutions allows them to create modern, personalized products or services for their customers much faster and more effectively. A positive coefficient value for the X_7 variable indicates that entities in the IT sector have a much higher chance of successfully transforming their value proposition than manufacturing or traditional service companies.

This stems from the fact that for IT companies, technology is the core of the business, not just a supporting tool.

In 2025, in Model 7, the impact of company size was revealed only in the area of key partners (Model 7). The (X_3) variable (large company) proved statistically significant. This result can be explained by the growing competitive advantage of the entire value chain. This is because AI tools make it easier for large companies to exchange data with suppliers. It is also possible that large companies have sufficient capital for supply chain digitization: digitizing common technology platforms, supply chain integration systems (e.g., advanced ERP/CRM systems combined with AI), and network security for secure data exchange; building common APIs and cloud databases; implementing automated ordering and logistics tracking systems; investing in algorithms that forecast demand for suppliers; and ensuring secure, encrypted data transmission channels between companies.

The conducted likelihood ratio (LnL) test analysis revealed a lack of structural stability of the logit model parameters between 2024 and 2025. The study results can be found in Appendix 3. For eight of the nine variables examined, the Chi-square test statistic clearly exceeded the critical value of 5.991. For these items (from item 1 to item 8), the null hypothesis (H_0) of parameter stability was correctly rejected at the significance level ($\alpha = 0.05$). This means that the impact of factors such as segmentation, value proposition, and key resources has changed statistically significantly over time. The exception is the "Cost structure" variable (item 9), for which the test statistic is 2.53, which is lower than the critical value. Therefore, there is no basis for rejecting the hypothesis (H_0) for cost structure, meaning that this parameter has remained stable.

The rejection of hypothesis H_0 in models 1 to 8 (from Segmentation to Revenue Structure) means that the mechanism of diffusion and mutual influence of AI technologies in these areas has completely changed over the course of just one year. This result can be interpreted as indicating that the market is in a phase of profound AI evolution. The way AI use in some areas drove its implementation in others in 2024 became obsolete in 2025. This is evidence of a dynamic digital transformation process. The market learns AI dynamically and, to some extent, chaotically. I am testing AI tools in 8 areas on a "living organism". However, there is something that serves as a benchmark: the stability of the cost-related model parameter, also known as the cost structure in the BMC model. The cost structure proved to be the most stable element in this study. This indicates that the mechanism by which AI tools implemented in the remaining 8 areas generate savings or shape company expenses has already been fully structured and automated. The impact of AI on cost optimization (e.g., process automation, reduced man-hours) in 2025 is based on exactly the same predictable relationships as the previous year. Cost algorithms deliver consistent, repeatable results. What does this mean? A company that implements AI more efficiently than its rival achieves cost leadership. AI is used to optimize costs or cut costs. It can also be argued that cost optimization becomes the first elimination criterion in the competitive game, not a permanent win. Those who fail to

optimize costs with AI are eliminated from the market. However, it's important to remember that if the AI tool is not dedicated, competitors will purchase the same AI tools and achieve the same cost optimization within a few months. A cost advantage with AI may provide a temporary advantage, but it is easily imitated by others. Therefore, companies will have to seek a pattern of applying AI tools in the remaining eight BMC areas to gain a market advantage. Currently, the lack of stability in these eight areas indicates that no one in the market has a ready-made template for success. Companies that develop a unique pattern of AI application in their business model should gain a market advantage over their competitors. Therefore, there is a need to continue this research in the coming years.

Referring to the quantitative study using logit models, it should be emphasized that the most difficult stage of digital transformation is taking the first step and implementing AI in any pilot area. Once the organization has developed internal procedures and competencies related to using algorithms (as reflected by the OtherBMCAI variable), the implementation process in the remaining business segments (in particular, in 2024 in the areas described by model 8: variable Y – Revenues, model 9: variable Y – Costs, model 5: variable Y – Key Assets, and model 3: Distribution Channels, and in 2025, model 2: Value Proposition; Model 8: Y – Revenues; Model Y-9: Costs. These models were the most valuable in formal terms) occurs organically and highly effectively. It is also worth noting that the developed models also allow for the implementation of a practical scale of technology adaptation:

1. Resistance Phase (0-2 implementations): The probability of success increases slowly. The company is learning the technology, and the barrier to entry is high. At this level, it is crucial to build competencies in AI tools if dissemination to other areas of the business model is to occur.
2. Hyper-growth/Breakthrough Phase (3-6 implementations): Each subsequent implementation significantly (even dramatically) increases the chances of digitizing the area under study using an AI tool. This is the phase in which the organization begins to operate in a process-oriented manner. Synergy becomes the main driving force. Reaching a critical mass of 4-5 areas indicates that the probability of the company adopting it in another specific area becomes higher than the probability of inaction.
3. Saturation phase (7-8 implementations). The probability approaches 1 (100%). Implementing AI in the researched area ceases to be a separate, risky project. At this stage, barriers to entry (both competency-based and psychological) are completely eliminated by prior experience.

The logit models also allowed for addressing hypothesis H1e and the sub-hypotheses H1e-a to H1e-d derived from it. The main hypothesis (H1e) was partially confirmed. Considering the results of testing the specific hypotheses, the main hypothesis H1e is considered partially confirmed. The empirical study showed that the likelihood of implementing AI in BMC components is significantly determined by the overall intensity of the organization's digitalization (H1e-a) and company size as a key structural characteristic (H1e-b).

4. Discussion

Research on the use of AI tools in enterprises from a business model perspective can contribute more knowledge not only in terms of theoretical implications but also in the area of practical application of AI in business. A systematic literature review related to the use of AI tools in business, as well as literature presenting research results on digital transformation, indicates the need for further research. Currently, research on the application of AI tools in enterprises in relation to their business models based on the BMC template is still in a phase where literature, conceptual and qualitative research predominate, and quantitative research is rare. However, it should be emphasised that it is thanks to research based on the first three methods, and in particular on the qualitative method as empirical, that we can seek confirmation of the latest results based on quantitative research. We must also not forget the valuable contribution of research based on a systematic review of the literature, the results of which constitute the first point of reference for further research on a given phenomenon. In turn, a large number of qualitative studies can be analysed quantitatively over time. Thus, they are another set that can show in which areas of the BMC template AI tools have been applied. Conceptual research, whose solutions may relate to specific areas of the BMC, can bring similar value. Thus, it also becomes an indicator showing which areas of the template are of interest for in-depth research. It is also worth mentioning the most important selected research works from the point of view of our study. The first one concerns a study conducted by Metzler D., Neuss N., Muntermann J. and refers to the applications of AI in business models of enterprises, in particular the use of AI as a driver of innovation within a given business model (Metzler, Neuss, Muntermann, 2021). The research was carried out in the form of a case study in four traditional industries. In this work, they sought to answer questions such as RQ1: How does the use of AI affect specific elements of the business models of companies present on the market? RQ2: How does AI drive innovation in the business models of companies present on the market? The study was based on expert interviews with senior management of eight companies in four industries: (1) Automotive, (2) Industrial products, (3) Pharmaceuticals, and (4) Consumer goods and retail. The study yielded results in which AI played the largest role as a driving force in areas such as key activities (processes), value proposition, key partners, and key resources. In our study, we obtained similar results for key activities (processes) and value proposition. On the other hand, key partners and key resources in our study are less important for companies, especially in 2024. It is not until 2025 that there are more YES answers in the area of key partners and key resources, but as the statistical test shows, these differences are not yet significant. In our study, after value propositions and key activities, customer relationships took the next statistically significant place. Several aspects should be noted when comparing the results of both studies. Firstly, it is interesting that there are two areas that stand out from the rest in terms of AI applications. These are value proposition

and key activities/processes. From the point of view of the qualitative study results, it was also possible to determine that the impact of AI on the value proposition concerns issues such as:

1) The development of products and services based on or supported by artificial intelligence.
2) Integration of artificial intelligence components into existing products and services.

In the case of processes, this concerned:

1) automation and optimisation of internal processes through artificial intelligence,
2) reducing the workload through human-robot collaboration based on artificial intelligence,
3) predictive analytics in the field of consumer needs and trend forecasting.

It should be noted that the results of the qualitative study were published in 2021. The consistency of the two areas (key activities, value proposition) with our research results in 2024 and 2025 allows us to hypothesize that in 2022 and 2023, interest in the application of AI tools was concentrated in these two areas. However, this hypothesis needs to be verified. Another issue is the difference between the third area of AI tool applications in the aforementioned qualitative study and the results of our quantitative study in 2025. In the case of qualitative studies, these are key partners. In the case of our quantitative studies, these are customer relations. In this case, we put forward two hypotheses that explain this difference. The first is that the introduction of AI tools such as ChatGPT in 2023 has led to a significant increase in the use of these tools for customer relationship building. The second hypothesis concerns the statement that the diffusion of AI tools among companies applying them in the area of customer relations lasted approximately 2 to 2.5 years. An observation was also made that the qualitative study selected traditional companies producing goods with a physical dimension. In such companies, e.g. in the automotive and pharmaceutical industries, relationships with suppliers within the framework of so-called horizontal integration are important in the area of product manufacturing.

Among other research results identified in a systematic review of the literature, an article by Ma Genoveva Dancausa Millán et al. entitled "An Economic Perspective on the Implementation of Artificial Intelligence in the Restaurant Sector" stands out. The authors of the article conducted qualitative and quantitative research. As part of the qualitative research, three groups related to gastronomy were surveyed – chefs, entrepreneurs and gastronomy experts – to gather their opinions on the use of artificial intelligence in the restaurant sector in Spain. The qualitative research used the Business Model Canvas and Lean Model Canvas, adapted specifically to the restaurant sector. These models, as innovative approaches, allowed for the identification of key success factors based on the respondents' experiences. The division based on the tool used was also interesting. The study was conducted using the Business Model Canvas, which the authors considered to be more focused on the market and the company, and the Lean Model Canvas, which prioritises the market and the product. The results of the qualitative study indicated that value propositions based on creating personalised menus using artificial intelligence algorithms and offering unique and personalised dining experiences stand

out as core values that attract and retain customers. Another area is customer relations and distribution channels, including an online platform for orders and reservations, as well as partnerships with restaurants and catering companies, which are essential for promotion, sales and service delivery. Next are the identified revenue streams and key resources, which include revenue generated from direct sales of personalised menus, commissions on orders placed through the online platform, and artificial intelligence (AI) consulting services for food service establishments. Key resources also include teams of AI developers, experienced chefs and a robust technology platform. Referring to the results of our 2025 study, we can conclude that there are again two common areas of BMC: value proposition and customer relationships. It is worth noting that the second important area, key activities and processes, is not explicitly mentioned, although the authors of the article claim in the part of the study where the Lean Model Canvas is used that "specific problems in the restaurant sector that can be solved with artificial intelligence, such as inventory management , menu personalisation and kitchen process optimisation, helping entrepreneurs strengthen their company's weaknesses and identify key factors, saving costs and improving investment efficiency". It is worth noting that this study, in correspondence with ours, suggests that in-depth research on the application of AI tools should focus on specific industries.

Among other studies, it is also worth mentioning Julian Marius Muller's article "Business model innovation in small- and medium-sized enterprises. Strategies for industry 4.0 providers and users " Müller JM. (2019). This article presents the results of a qualitative study. The aim of the study was to examine the impact of Industry 4.0 on the business models of SMEs in the manufacturing sector. Although Industry 4.0 includes other technologies in addition to AI tools, our research shows that AI technologies interact with such Industry 4.0 technologies as: IoT, Digital Twin, Cloud Computing, and Robotics. Therefore, it is worth citing the aforementioned study. A representative sample was selected to conduct the qualitative study. The study covered the mechanical and machine construction industry, the automotive industry and the electrical industry. The article concluded that these industries would be most affected by Industry 4.0. Therefore, these three sectors were selected for the study. The study included interviews that focused on changes in the business model in connection with Industry 4.0. A total of 43 interviews were conducted. Of the 43 companies, 24 were from the mechanical engineering and equipment industry, 13 were automotive industry suppliers, and 6 were from the electrical sector. The study showed that key resources were the most frequently mentioned component in the sample (58.14% of respondents). Respondents mainly mentioned two aspects. Firstly, production facilities and equipment must be modified or specially purchased in accordance with specifications, or existing machines must be adapted, also known as "modernisation". This is a very interesting result, as it is somewhat related to the view of the application of various Industry 4.0 technologies not only in relation to the acquisition of new assets but also in relation to their integration with existing ones. In our study, key resources begin to play a role in 2025. Most companies indicate the use of AI tools in key resources,

but this is not yet a significant difference compared to companies that do not use AI tools in this area. Value proposition is the second most frequently mentioned component (53.49% of respondents). Respondents mainly describe new products, services or a combination of both, to be offered to customers. In our research, the value proposition is also of significant importance. Key partners rank third on the list of the most frequently mentioned components (48.84% of respondents). According to respondents, IT experts are important for the implementation of Industry 4.0 solutions. In our research, relationships with key partners begin to be recognised in 2025. However, as with key partners, we see greater use of AI tools in companies in this area, but not to the extent that it is significant compared to companies that do not use them. In turn, the results of Julian Marius Muller's study Müller JM. (2019) indicate that it is worth examining key partners from the point of view of AI tool providers in the future. Customer relations also rank third on the list of the most frequently mentioned structural elements (48.84% of respondents). Similarly, in our study, this area is important in relation to the use of AI tools in 2025. However, from the perspective of Industry 4.0, customer relations in Julian Marius Muller's study Müller JM. (2019) are more focused on the reliability of Industry 4.0 technologies. What is interesting, however, is the difference in Julian Marius Muller's study, which shows that key activities are the second least frequently mentioned components of the business model (23.26% of respondents). In our research, key activities in the area of processes played an important role in AI applications in both 2024 and 2025. This is an interesting difference that requires further research in the future.

In the case of the quantitative study using logit models based on the collected empirical data for the entire BMC framework, it should be emphasized that it was an extension of previous fragmented studies in the area of digital transformation using other research methods. In this respect, the study stands out from others – it uses logit models to empirically operationalize the entire Business Model Canvas (BMC). It is worth emphasizing, however, that the study fits into the trend of econometric analyses of innovation diffusion, including digital innovation, but transfers it to the level of the full BMC framework. It is worth mentioning here slightly older articles focusing on the diffusion of technology, such as: Inter- and Intra-Firm Diffusion Of Ict In The United Kingdom (Uk) And Switzerland (Ch) An Internationally Comparative Study Based On Firm-Level Data, Giuliana Battisti, Heinz Hollenstein, Paul Stoneman, Martin Woerter (Battisti, Hollenstein, Stoneman et al., 2007) or Inter- and intra-firm diffusion of technology: The example of E-commerce: An analysis based on Swiss firm-level data Heinz Hollenstein, Martin Woerter, (Hollenstein, Woerter, 2008). Among other recent scientific studies, one should undoubtedly mention The Influence of Generative AI on Business Management by Rodríguez Benito, M.E., Hernández Zelaya, S.L., Reyes Reina, F.E. (Rodríguez, Hernández, Reyes, 2026) where the authors developed a logit model that predicted the probability of a company implementing a broad portfolio of AI technologies (binary variable: implementing at least two different AI typologies simultaneously), based on the fact of prior adoption of Generative AI as a starting point. Another interesting article is Applications

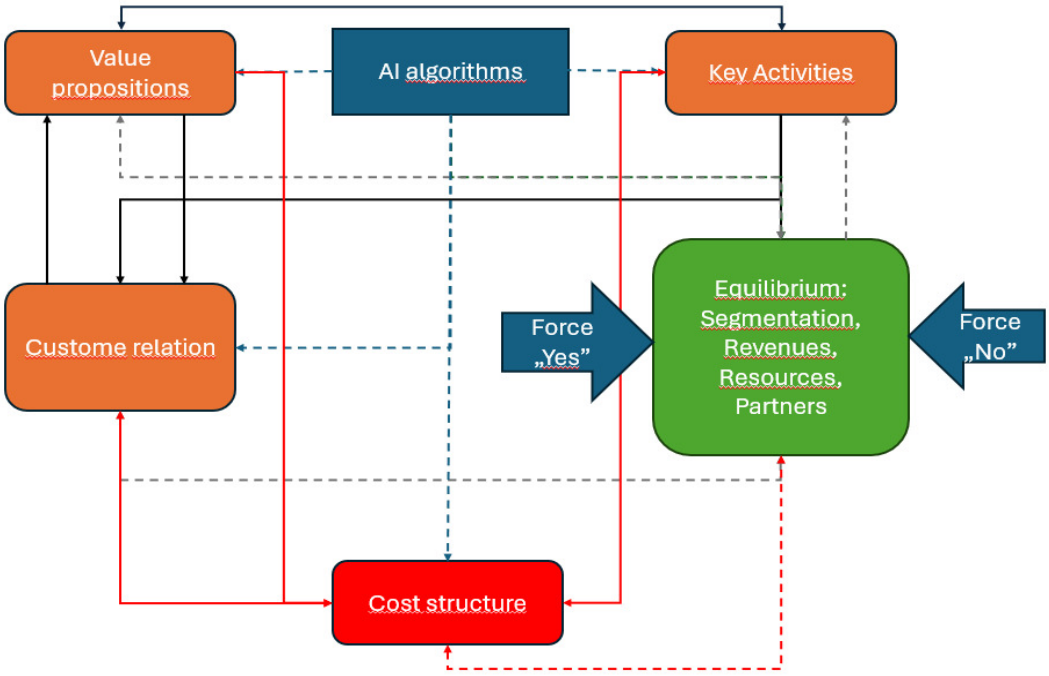
of Artificial Intelligence in Small and Medium Scale Business (Kamruzzaman, Sujoy, Siddiki et al., 2025). As part of this article, econometric models were developed that revealed a strong influence of organization size on the probability of advanced AI diffusion. The study showed that medium-sized companies are statistically twice as likely to fully implement Business process remodeling under the influence of AI is more likely than microenterprises.

The study using logit models revealed interesting results regarding the involvement of large enterprises in AI adoption in terms of resources in 2024 and key partnerships in 2025. Although company size was a noticeable factor in the study, it cannot be ruled out that small companies are experiencing asymmetric, spotty implementations, while large corporations are implementing AI systematically. This interpretation is consistent with the information contained in the reports AI adoption by small and medium-sized enterprises: Emerging gaps across G7 and OECD economies (OECD, 2025) and Use of artificial intelligence in enterprises (Eurostat, 2025). This indicates the need for more detailed research on the use of AI tools by SMEs.

As part of the discussion, we also consider the research results regarding the hypotheses and the resulting conclusions. In summary, quantitative research based on the 2024-2025 series of tests demonstrates a dynamic evolution in AI implementations, with key areas including processes and value propositions, as well as customer relationships. This change, supported by the lack of structural stability of logit model parameters in as many as eight BMC areas, signals a deep, even chaotic, search by companies for a unique template for market success. The only stable element proved to be the cost structure, proving that the mechanisms for automation and cost optimization using AI have been mastered. In the context of competitive strategy, however, this means that cost reduction has become merely a fundamental criterion for survival (easily replicated), not a source of sustainable success. Ultimate strategic advantage will be achieved by those organizations that develop their own, difficult-to-imitate model for AI use in the remaining, still unstable business areas, one that is not only focused on cost-based competitive advantage but is primarily based on market advantage. The series tests indicate that the aforementioned areas—value proposition, processes, and customer relationships—may be the first to emerge from these volatile areas in the future. However, this requires further research in the coming years.

As part of our discussion of the results, we also propose a working model of the AI causal engine within BMC. The overwhelming statistical significance ($p < 0.05$) and clear dominance of "YES" indicate that the model's key components are the Value Proposition and Key Activities/Processes area, as well as the cost/cost structure area, which reflects companies' current efforts to gain cost-based competitive advantage. In the proposed model, AI tools are essentially the key driver of impact. Cost optimization using AI is the first step and the primary goal of companies. In turn, series tests indicate that in the early stages of diffusion, organizations implement AI where the return on investment is immediate: internal operational efficiency (processes) and product or service improvement (value proposition) are among these.

Data from 2025, in turn, reveal the emergence of a new important area: Customer Relationships are moving into a statistically significant dominance of "YES" ($Z = 2.329$, $p < 0.05$). Companies are exploring these three areas to use AI to build a competitive market strategy.



The blue dashed line indicates the impact of AI algorithms on 4 key BMC areas: value proposition, key activities/processes, customer relationships, costs; the green dashed line shows the overall impact of AI algorithms on areas in equilibrium; the black arrows show the relationships between the 4 BMC elements; the gray dashed line shows the relationships between the 4 elements and the 4 elements in equilibrium; the red line shows the relationships between the 4 areas: value proposition, key activities/processes, customer relationships, and costs; the red dashed line shows the relationships between costs and the 4 areas in equilibrium.

Figure 9. AI Causal Engine Model for Business Models.

Source: Authors own work.

The causal mechanism is the democratization of generative AI, primarily LLM architecture. Unlike complex, often dedicated AI tools in the supply chain, customer-facing AI tools, such as chatbots and CRM systems with generative AI, are highly effective. Consequently, the causal impact of AI shifts from internal processes directly to the customer, explaining the statistical significance of customer relationships in 2025. The six areas in which equilibria occur in 2025 remain controversial. It cannot be ruled out that these are due to sample limitations, but the fact that significant effects occur for the areas of value proposition, processes, and customer relationships demonstrates that equilibria can be considered in terms of the interaction of forces responsible for the implementation of AI tools in BMC areas, as well as the interaction of forces responsible for the lack of implementation. The former include: market and competitive pressures, customer needs and expectations, the desire to reduce operating costs, management's awareness of digitalization, evolving employee attitudes towards digital transformation, employee digital competencies, government-created conditions (programs supporting digital transformation among enterprises), and others. The latter include: technological debt, low data

levels, low competencies, especially digital competencies, financial barriers, an unclear business model, resistance to change, risk, and others. These two forces may block AI expansion in other areas of BMC. It cannot be ruled out that the transition to AI expansion for many companies requires a profound reorganization that goes beyond the technical installation of AI tools. The proposed working model of the AI engine requires further research, which will primarily demonstrate whether the six areas mentioned will remain in balance or whether they will be incorporated into areas where AI tools are used or not.

Based on the obtained results of the logit models, the verification of the hypothesis regarding company size is crucial. This clearly indicates that large organizations demonstrate significantly higher dynamics and effectiveness in adopting AI tools. Basing these findings on the classical resource-based view (RBV), it can be assumed that larger entities possess unique, difficult-to-copy technological, human, and structural capital. Even if they use readily available AI tools, they master them more quickly thanks to their human resource competencies, their tendency to be a digital organization, a learning organization, and their propensity for digital innovation. It is precisely this configuration of resources and competencies that allows them to build market asymmetry and achieve a sustainable competitive advantage, and perhaps even a market advantage in the future. Consequently, a distinct polarization may occur in the market: companies capable of transforming AI potential into unique strategic value will begin to clearly outperform their competitors.

Using the scale of technology adoption, the overall research results can be discussed. In 2024, most companies were in the resistance phase (implementation in only two areas: processes and value proposition). In 2025, thanks to the addition of customer relationships and dynamic trial tests in other areas, such as segmentation or resources, companies entered the initial hypergrowth/breakthrough phase (3-6 areas). The explanation for the lack of structural stability (LnL tests) indicates that the hypergrowth phase is inherently chaotic, dynamic, and based on real-world experiments with AI tools. This explains why the parameters of the logit models for the eight BMC areas proved unstable between 2024 and 2025 – the market learns as it transitions from phase 1 to 2. The scale also links to the Resource Based Value (RBV) and large companies. Reaching the saturation phase (7-8 areas) requires enormous capital and unique competencies. This is confirmed by the result of the logit model on company size: only large organizations have the resources to enter this phase currently and thus maintain a sustainable competitive advantage, while smaller companies are in the resistance or transition phase.

5. Summary

The study, based on a systematic literature review, allowed us to identify which technologies are interesting from the perspective of AI tool applications and which of the nine BMC areas are most frequently used. The systematic literature review thus provides insight into the appropriate selection of research methods for further research, and also provides insight into which AI application areas within BMC should be selected for, for example, in-depth studies.

The quantitative survey-based study yielded unique results, demonstrating changes in enterprises regarding the non-use and use of AI tools in specific BMC areas. The study captured a crucial moment of digital transformation in the area of AI applications in specific BMC areas. As recently as 2024, most enterprises were not interested in using AI tools in specific BMC areas. Only the key activity areas related to processes and value propositions indicated that most enterprises were using AI tools. However, in 2025, the situation is changing in favor of AI tool adoption among enterprises. In addition to the two areas mentioned above, customer relationships will be added in 2024. In the next four areas: customer segmentation, key assets, and partner relationships, we see a higher number of companies using AI than those not using it. However, the differences between these companies are small, confirming the statistical insignificance. There are also areas where a slight majority of those not using AI tools remain. These include distribution channels, revenues, and costs. However, the differences are also too small, as statistically confirmed. This study indicates that significant changes are taking place in the use of AI tools in companies' business models. Based on the results, we can expect that in 2026 and 2027, a significant shift towards a majority of companies using AI tools should be observed. It would be a significant surprise to see a shift away from the use of AI tools. It does not seem that such a scenario will occur in the form of some form of "AI winter". However, further quantitative research is planned to confirm the direction of change. In turn, logit model studies from 2024-2025 indicate that the use of AI tools in BMC areas is a universal factor stimulating digitization through a feedback effect. This creates conditions for increasing employee competencies in AI tools and also reduces the psychological barriers to using new technology. It is worth emphasizing that both competencies related to the use of AI tools and reducing the psychological barriers associated with using these tools are interesting research topics. The results of quantitative studies using logit models indicate that large enterprises demonstrate an advantage in AI adoption due to greater capital resources, optimizing key resources (2024) and key partnerships (2025).

The quantitative study, conducted using both batch tests and logit models, can also be considered jointly in terms of common conclusions. The starting point is triangulation, which allows for combining these conclusions. In this respect, the study answers the questions "Where?" and "How does it work?" The batch test answered the question "Where" (in which BMC areas) is the AI activity of companies concentrated, i.e., Value Proposition, Processes,

and Communication. Logit models, in turn, revealed the mechanism and consequences of this concentration. They showed how implementations in some areas influence the probability in others. Drawing analogies from a systemic perspective, one can say that the quantitative study based on batch tests indicated what was happening in the system areas at time t, while quantitative study 2 showed how these areas interacted. For example, the key processes area is key in the batch tests, but the logit model, in which this area was the Y variable, was not a model that distinguished itself from the others in formal terms. This is also understandable in terms of the company's business model, which implements AI in processes not to "have processes", but to reduce costs, improve the value proposition, and increase revenue. Processes are the engine, not the result, although this engine is integrated into the synthetic variables of the degree of digitization based on AI tools. In turn, the value proposition, which is key in both the series tests and the logit study in 2025, allows us to conclude that companies are experimenting with AI in this area (series test), and the overall level of digitization based on AI tools in the company strengthens this area.

From the perspective of logit models, it's worth paying attention to large enterprises, particularly in the context of the resource-based theory. Large companies have sufficient resources to implement AI tools. However, what may limit them in implementing AI are employee competencies in using AI tools. This isn't just about technical understanding of the tool, although this is also important, but also a broader context of competencies, including soft skills such as critical thinking, creativity, curiosity, willingness to experiment, systems and process thinking, adaptability and openness to change, perseverance, and patience, allowing the tool to be used to increase the efficiency of workplace processes within a given business model and the implemented corporate strategy. However, if the resource-based theory removes the limitation related to AI tools and makes them readily available, then employee competencies become a key factor, crucial for the implementation of AI tools not only in large enterprises but also in SMEs. Furthermore, new models for transforming knowledge regarding the use of AI tools in organizations will also play a significant role. Companies that employ highly skilled AI-enabled employees and incorporate knowledge transformation mechanisms related to AI application into their business models will have a competitive and market advantage. However, this requires further research.

The results of the study, conducted using both series tests and logit models, including parameter stability, allowed us to build a situational picture of how companies are implementing AI tools in their business models. Currently, it can be concluded that companies are focusing on using AI tools to optimize their cost structure. This is the first concrete step towards achieving tangible results from AI tools as part of their so-called competitive strategy. The study results indicate that companies are dynamically testing various AI tools in various areas of their business models. It can be concluded that, on the one hand, they are learning them, and on the other, they are trying to implement them for a specific purpose within the existing business model and strategic assumptions. It is worth noting that a cost-based competitive

strategy has its limits. Companies will need to seek applications for AI tools for market strategy, which requires the application of AI tools in other areas of the BMC. The study results in the testing area indicate that these areas may include value propositions, customer relationships, and also processes. It is therefore important to continue research on the use of AI tools in various business models in order to capture not only the diffusion process within the organization but also to observe how the use of these tools may change at the level of the implemented strategy, i.e. the transition from a cost-based competitive strategy to a market strategy based on, for example, value proposition, customer relationship, or appropriate segmentation.

The results of the study, based on a systematic literature review and a quantitative survey, indicate that further research into AI BMC applications is worthwhile. In particular, it is worth focusing on selected individual BMC areas, such as distribution channels, or conducting studies on different configurations of areas, such as the front office or back office. From the perspective of implementing this study, it is necessary to consider its limitations. One such limitation was the design of the survey, in which we used YES/NO responses. From the perspective of the obtained results, this choice allowed us to capture the change in the use of AI in business models and also enabled the construction of logit models. On the other hand, expanding the survey with questions such as: "What specific tools do companies use in a given BMC area?" could contribute to a better understanding of which tools and in which areas of BMC play a key role.

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Appendix I

Year 2024			Independent variables statistically significant (p<0.05)																	
Lp.	Model	Variable Yi	Variable X1 - small company	Variable X2 - medium-sized company	Variable X3 - large company	Variable X4 - Application of AI in other areas of BMC	Variable X5 - Service or manufacturing company	Variable X6 technology company or other	Variable X7 - IT company or other	const	OR - Odds Ratio	Confidence Interval for the Odds Ratio (95% CI for OR)	Pseudo R^2 (McFadden)	Test H-L (-value)	Accuracy (ACC)	Sensitivity (TPR)	Specificity	Indicator (AUC)	Indicator (AIC)
			Coefficients standing next to variables																	
1	Model 1	Segmentation	-	-	-	0,6076	-	-	-	-2,7124	1,836	[1,555;2,167]	0,3064	0,73	80%	60,80%	91,30%	0,8452	186,832
2	Model 2	Value Proposition	-	-	-	0,6559	-	-	0,8040	-0,9619	1,927;2,234	[1,512;2,455]	[1,082;4,615]	0,2594	0,0429	79,90%	86,50%	61,00%	0,8295	185,682
3	Model 3	Distribution Channel	-	-	-	0,6507	-	-	-	-3,5974	1,917	[1,609;2,284]		0,349	0,5208	84%	63,20%	92,30%	0,8701	159,628
4	Model 4	Customer Relationship	-	-	-	0,691	-	-	-	-2,6088	1,966	[1,651;2,412]		0,3383	0,061	76%	66,70%	82,80%	0,8686	184,064
5	Model 5	Key Resources	-	-	2,0139	0,7756	-	-	-	-3,4452	7,492;2,172	[1,789;31,379]	[1,760;2,680]	0,4073	0,3699	82%	68%	90,40%	0,8835	162,836
6	Model 6	Key Activities	-	-	-	0,4809	-	-	-	-0,8269	1,617	[1,373;1,905]		0,1868	0,0924	69%	76,90%	57%	0,7786	222,252
7	Model 7	Key Partners	-	-	-	0,6165	-	-	-	-2,7513	1,852	[1,567;2,190]		0,3119	0,0171	79,50%	59,50%	91,30%	0,8433	185,37
8	Model 8	Revenue Structure	-	-	-	0,8363	-	-	-	-4,6882	2,308	[1,847;2,884]		0,4547	0,0912	88,50%	73,60%	93,90%	0,9036	130,112
9	Model 9	Cost Structure	-	-	-	0,7888	-	-	-	-4,2404	2,201	[1,787;2,710]		0,427	0,1454	87,50%	70,20%	94,40%	0,891	140,97

Appendix II

Year 2025		Independent variables statistically significant (p<0.05)																		
			Variable X1 - small company	Variable X2 - medium-sized company	Variable X3 - large company	Variable X4 - Application of AI in other areas of BMC	Variable X5 - Service or manufacturing company	Variable X6 technology company or other	Variable X7 - company or other	const	OR - Odds Ratio	Confidence Interval for the Odds Ratio (95% CI for OR)	Pseudo R^2 (McFadden)	Test H-L (-value)	Accuracy (ACC)	Sensitivity (TPR)	Specificity	Indicator (AUC)	Indicator (AIC)
Lp.	Model	Variable Yi	Coefficients standing next to variables																	
1	Model1	Segmentation	-	-	-	0,7575	-	-	-	-3,5031	2,133	[1,721;2,644]	0,4311	0,1562	81,30%	83,30%	79,20%	0,9033	126,23
2	Model2	Value Proposition	-	-	-	0,898	-	-	-	-1,2725	2,455	[1,785;3,376]	0,4442	0,4797	85,20%	90,70%	67,60%	0,9140	98,692
3	Model3	Distribution Channel	-	-	-	0,6671	-	-	-	-3,5463	1,949	[1,607;2,363]	0,3725	0,1988	77,40%	73,90%	80,20%	0,8876	137,658
4	Model4	Customer Relationship	-	-	-	0,701	-	-	-	-2,4006	2,016	[1,643;2,473]	0,3995	0,3365	80,60%	83,90%	75,80%	0,8912	129,282
5	Model5	Key Resources	-	-	-	0,5611	-	-	-	-2,5256	1,753	[1,486;2,067]	0,3129	0,036	75,70%	77,20%	73,70%	0,8580	151,608
6	Model6	Key Activities	-	-	-	0,5718	-	-	-	-0,7229	1,771	[1,447;2,169]	0,2941	0,0552	82,60%	88,80%	64,10%	0,8589	127,434
7	Model7	Key Partners	-	-	1,8685	0,7457	-	-	-	-3,3437	2,108;6,479	[1,701;2,612];[1,353;31,027]	0,4216	0,1454	81,30%	83,10%	79,20%	0,8996	129,83
8	Model8	Revenue Structure	-	-	-	0,8444	-	-	-	-4,4309	2,326	[1,825;2,964]	0,4659	0,2584	83,20%	80,00%	85,90%	0,9146	117,99
9	Model9	Cost Structure	-	-	-	0,8925	-	-	-	-4,2737	2,441	[1,892;3,150]	0,4967	0,1305	83,90%	85,50%	82,30%	0,9270	112,114

Appendix III

No.	Variable Name Yi	K - Degrees of Freed	Adjusted LnL 2025	Statistic χ^2	Critical Value α=0,05	Test Result
1	Segmentation	2	78,858	24,916	5,991	Rejection H_0
2	Value Proposition	2	61,092	62,253	5,991	Rejection H_0
3	Distribution Channel	2	86,231	16,830	5,991	Rejection H_0
4	Customer Relationships	2	80,827	18,410	5,991	Rejection H_0
5	Key Resources	2	95,231	26,000	5,991	Rejection H_0
6	Key Activities	2	79,635	58,982	5,991	Rejection H_0
7	Key Partners	2	83,672	14,025	5,991	Rejection H_0
8	Revenue Structure	2	73,542	20,970	5,991	Rejection H_0
9	Cost Structure	2	69,751	2,530	5,991	Not rejection H_0

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ANALYSIS OF TRANSPORT NETWORK PERFORMANCE USING SIMULATION TOOLS

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Purpose: The paper presents the results of the analysis of the transport network performance using simulation methods and tools.
Design/methodology/approach: The transport network was modeled using FlexSim computer software. The analysis involved creating two simulation models of the conveyor network. The first, or baseline, model was based on non-accumulating conveyor technology at workstations, while the second model included accumulating conveyors.
Findings: Modeling transportation networks using computer software allowed us to design and select the most optimal transportation system for the company. Simulation studies showed that changes introduced to the baseline model improved system performance, increasing the number of filled order bins by approximately 67%, without significantly increasing warehouse space.
Originality/value: Simulation tools enable the proper structure of a conveyor system to be determined at the design stage, allowing for accurate performance and cost estimation, as well as for system refinement before installation in real-world conditions.
Keywords: computer simulations, modeling, FlexSim, performance improvement, transportation networks.
Category of the paper: Case study.

1. Introduction

Developing an effective conveyor network model is essential to streamline logistics processes. In this paper, the so-called basic conveyor network model and the improved model were analyzed. The work included creating a technical flow diagram within the conveyor network, followed by a simulation model in FlexSim. The result was a fully functional simulated model, which was then subjected to qualitative and cost evaluation in the final analysis. According to researchers in the field, designing conveyor networks involves choosing the layout of the lines, controlling material flow, and minimizing energy consumption (Susanto

et al., 2020). Analysis of results presented in the literature shows that designing an efficient transport network requires combining precise flow models (Suchorab-Matuszewska et al., 2025; Mallah et al., 2023) with optimal belt speed control (Pihnastyi et al., 2023; Suchorab-Matuszewska et al., 2025 and energy management with the network of routes and storage levels (Kawalec et al., 2020). Key factors ensuring optimal performance include a high fill rate, proper drive configuration, large buffer tanks, and advanced routing and control algorithms. One of the main tools in designing and optimizing conveyor transport systems is simulation methods. They allow testing designed systems, identifying so-called bottlenecks, and adjusting operational parameters without interfering with actual operations (Bobinics, Marasova, 2025; Hrnickova et al., 2025; Husar et al., 2024; Lilja, Olsson, 2019; Szntesi, Tamas, 2023).

2. Description of the conveyor transport network system

The subject of the analysis in this study is a conveyor network serving as a storage and component picking system for production purposes. This system is the so-called automated Person-To-Good picking method (the employee collects specified quantities of goods), which involves placing the conveyor network in a shelving storage area and positioning flow racks above the conveyor. The operator managing the picking station waits for the arrival of a container with an order, then collects the appropriate quantity of components into the production container and confirms the picking. When the container stops at the station, LEDs controlled by the pick-by-light system illuminate the locations from which the operator is to pick a specified number of components. From the pick-by-light screen, the operator reads how many units of a given component need to be taken and placed into the production container. The action is confirmed by pressing a button on the location screen. When the system receives confirmation that all components have been collected at the assembly station, it automatically replaces the assembly container.

The system is divided into two storage methods: flow racks and shelves. In the flow rack section, production components that are picked most frequently are stored, so they are located closest to the picking station. The other storage method is shelves, which are located behind the operator. The shelves hold items with medium and low turnover.

To design a fully functional logistics model, in addition to the picking area, the following zones are also considered:

- order start – the zone where the container is generated and the order is assigned to the container by scanning at the loop entry,
- decanting – the process of repackaging items into plastic containers handled by automation,

- flow channels – this is the storage area for the fastest-moving items, which the operator has direct access to,
- shelves – the zone where the operator manually picks items from standard shelves, the downloaded items are classified as medium and slow-moving items.

3. Methodology

Simulation methods were used to analyze the efficiency of transported cargo units. In the simulation software, a logistics installation designed to support the component picking process for production was modeled. For research purposes, the FlexSim software was chosen due to its lower level of technical complexity compared to other programs of this type. Other programs that allow the construction of an identical research model require a good knowledge of programming languages. FlexSim, in terms of functionality, is not inferior to more advanced programs, but it allows simulation models to be built in a simplified way. The simplicity of this program lies in pre-defined simulation objects, which already contain programmed functionalities that can be modified through the user panel. FlexSim software is more oriented toward ease of use when creating models (FlexSim, 2017). Due to its license-related limitations, FlexSim software allowed for setting up a maximum of 100 objects in the simulation model. This limitation resulted in certain less significant processes, which do not considerably affect the performance of the entire installation, being generalized. Generalization involved representing several interacting objects in the real model with a single object in the simulation software. The introduction of generalization, that is, reducing the number of objects, did not affect the results of the present study, as the objects still performed their function, while their visualization was simplified.

After building the baseline model of the logistics installation in FlexSim software, all parameters defining the operation of the objects within the logistics model were modified. A key aspect was determining the cycle times of individual activities or tasks, that is, how long a given container would be handled during order picking, or specifying the time intervals, known as takt time, i.e., how often a given container would be released to the installation. The release takt time was calculated based on the assembled mass.

The next step was the experimental phase, in which the efficiency of the installation was examined for different takt times and process cycles. Two variants were analyzed:

- the number of containers with assembled components that left the installation within an hour, a shift, and a full day,
- the number of containers that were sent as replenishment to picking locations, also within an hour, a shift, and a full day. After the experimental phase, which allowed the identification of system bottlenecks, the model was improved and the efficiency of the installation was re-examined for different cycle times and process cycles.

4. Designing the base model

The first step in building a model for simulation studies was creating a base with a conveyor system using Visio software. The base was then loaded into FlexSim software and scaled according to the dimensions given in Visio. The main goal was to keep the natural dimensions so that all the presented conveyor sections were represented at a 1:1 scale. A functional model of the transport conveyors is shown in Figure 1.

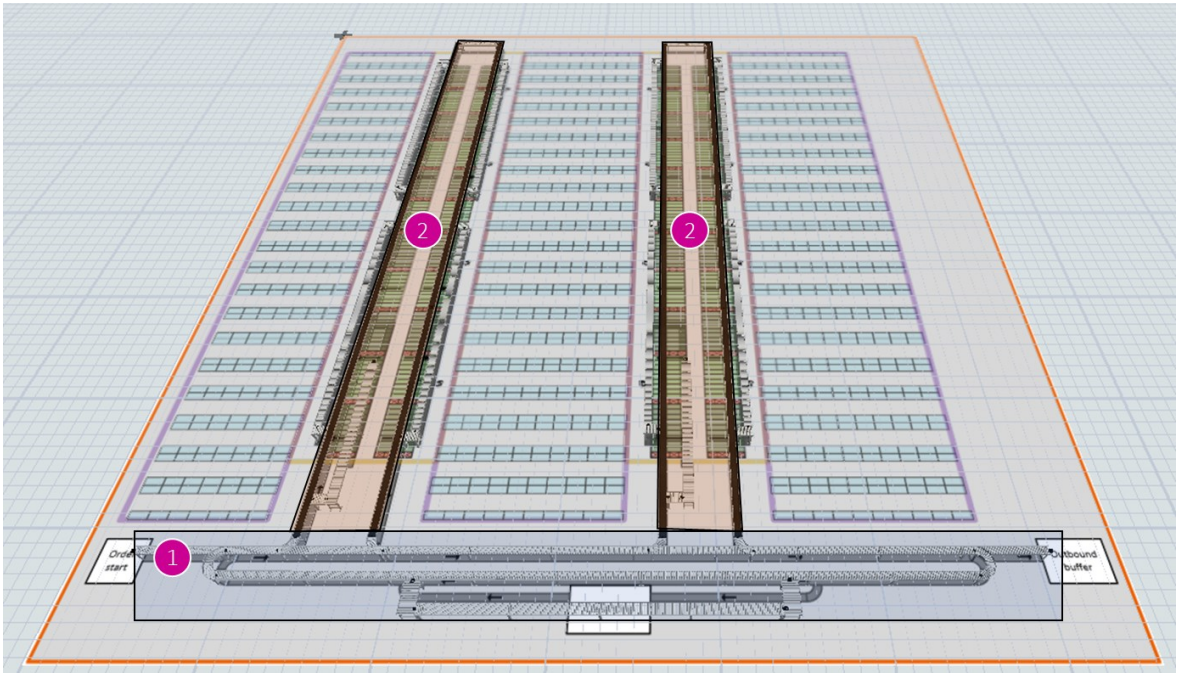

Figure 1. Conveyor system of the base model: 1 – main conveyor loop, the so-called conveyor highway responsible for distributing flow between functional zones, 2 – conveyors with flow racks.

Source: Own elaboration using the FlexSim program

The next step, after creating a complete network of conveyors, was to place fixed resources within the system. The main resource consists of containers, which represent actual flow within a real conveyor installation. Fixed resources in FlexSim software are not only elements that generate flow but also those that receive flow from the installation, in order to simulate a container exiting the installation, because in the real model a container, after completing all picking tasks in the installation, is directed to the exit. Typically, depending on the type of installation and its purpose, the exit for such a container may be directly to another department within the enterprise, e.g., production, or in the case of order picking for the end customer, these types of containers are directed to the palletization area, from where they are later transported to the loading gate. In this work, the installation is intended for assembling production components, so the transport takes place to the production area, where the final product is assembled from the aforementioned components. Inside the installation, there are several key elements that generate resources or, in the case of a sink, take resources from the installation.

One of the main elements is the "Order start" – the starting point where containers with orders are generated. Another main element of the model is the so-called sink, which is an object responsible for taking the flow out of the installation. If any material is put into the sink, it disappears from the conveyor installation and only exists in memory as a countable resource. The last key element that generates resources in the conveyor installation is an object responsible for simulating the generation of empty containers in the installation. Empty containers in the system are generated during the picking process because components are picked from containers used for storing materials, and as the process progresses, these containers get emptied. At that point, the picking station operator takes the empty container from the picking location and places it on the conveyor. The conveyor then transports these containers to the repacking station, where they are held until the repacking process starts.

To create flow logic, it was proposed to generate labels. In the FlexSim program, a label can be assigned to any resource at the moment of its creation or the label can be changed during the process. The third option is to set the so-called probability, in which percentage parameters are determined to specify the likelihood that a source will release a resource with a particular label. In the presented case, containers with two labels are generated. Each label has an equal probability of appearing, as it is distributed 50%/50%.

5. Identification of the causes of performance limitations of the modeled transport network system

To examine the performance of the described installation, certain operating parameters for the simulation model were created and the operating time was determined. Based on this, optimal parameters were identified, showing the maximum performance of the installation, meaning the flow that can be effectively handled by the system. When one unit has high performance and another has low performance, that unit becomes a bottleneck. Compiling all bottlenecks and device performances constitutes what is called system performance, which is the maximum capacity of the installation, determined by the limitations of the weakest elements.

As a result of analyzing the modeled transport system, the following bottlenecks were identified:

Intersection point at the order start and decanting loop – the intersection constitutes a bottleneck when other constraints cause flow disturbances. This means that the indicated case is not the main cause of limiting the plant's capacity but may be one of the potential points where flow can be halted if other bottlenecks lead to flow stoppage.

Non-accumulating conveyors - a limitation may occur when the system is loaded with too many containers. The interaction of transfer conveyors with non-accumulating conveyors can lead to downtime when the conveyors are overloaded. This is one of the potential downtimes that have a significant impact and may cause bottlenecks in less critical points by disrupting the flow continuity. Analysis indicates that non-accumulating conveyors significantly reduce the technical efficiency of the entire system and decrease the buffering potential of the installation.

Buffer before the repacking stations – if too many containers build up here because they can't be transferred to the picking station, the entire system will stop. Holding containers at this point has a big impact on the whole operation since it causes the main loop to get blocked, which stops the flow. If the simulated overload above isn’t fixed by manually removing containers from the conveyor, it will lead to downtime for the entire system. Fixing this kind of situation can take several hours because the system needs to restart and get back to its full flow capacity.

6. Base model improvement

Based on the identified bottlenecks, improvements to the simulation model were proposed. The main bottleneck significantly affecting the technical performance of the entire installation was the use of non-accumulating conveyors. As a solution to this problem, it was decided to

use accumulating conveyors equipped with drive rollers powered by an electric motor, so-called motor rollers (Figure 2). The use of this type of equipment allowed for minimizing downtime.

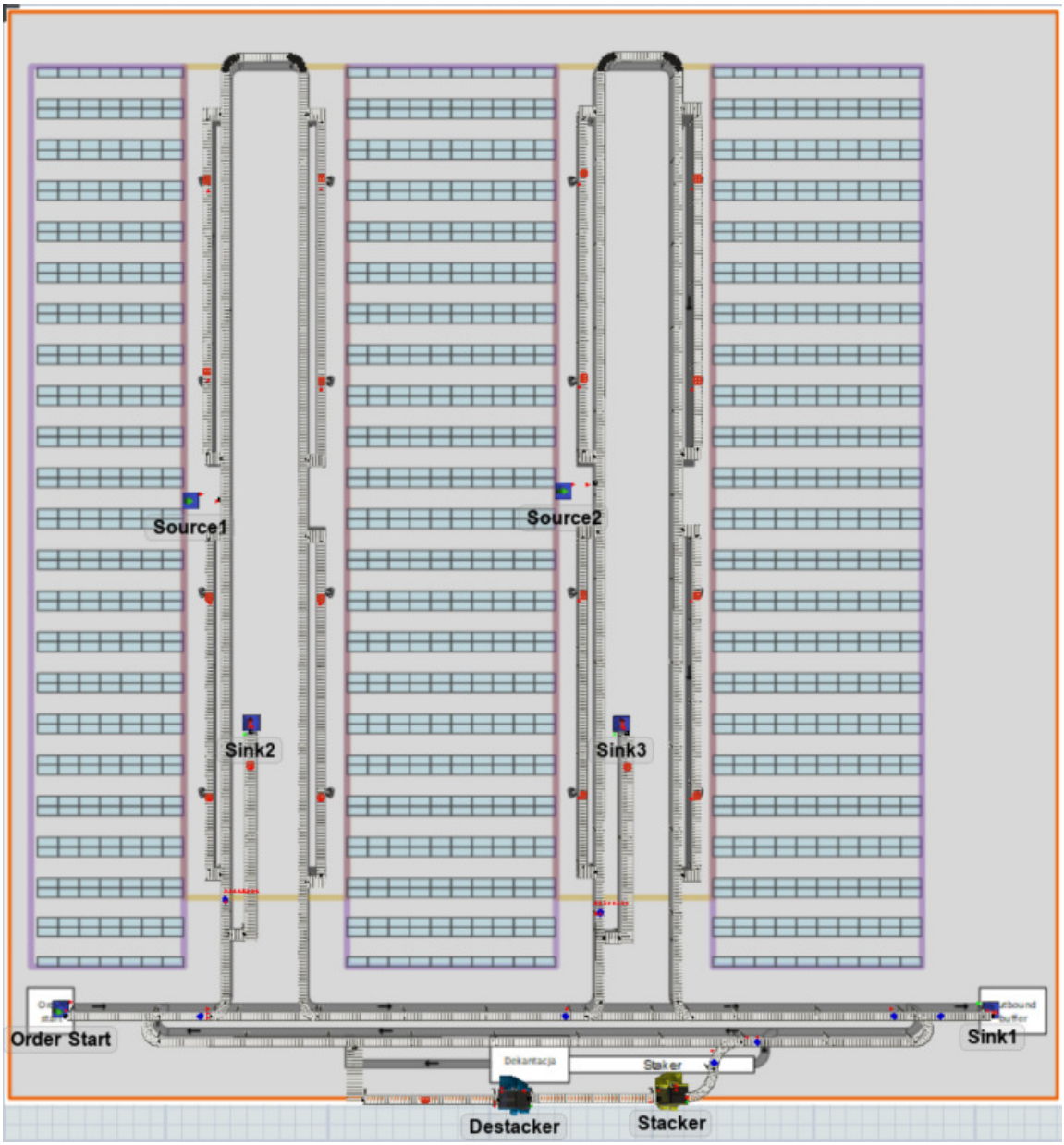

Figure 2. Improved simulation model.

Source: Own work

To increase buffer capacity, a model was developed that utilizes stacking devices. Stacking means that a container is delivered to an elevator, which raises the stack of containers. When the next container stops at a designated location, the stack is placed inside the container and lifted again. Depending on the device used, this type of solution allows for the creation of stacks of 10-20 containers high, which in the largest variant allows for an increase in buffer capacity by approximately 20 times. The overall concept for increasing buffer capacity involves the use of a stacking device at the input, which creates consolidated load units and transports them in stacks along a conveyor (Figure 3). After buffering, the containers are directed to a destacking device, which is responsible for separating the load units.

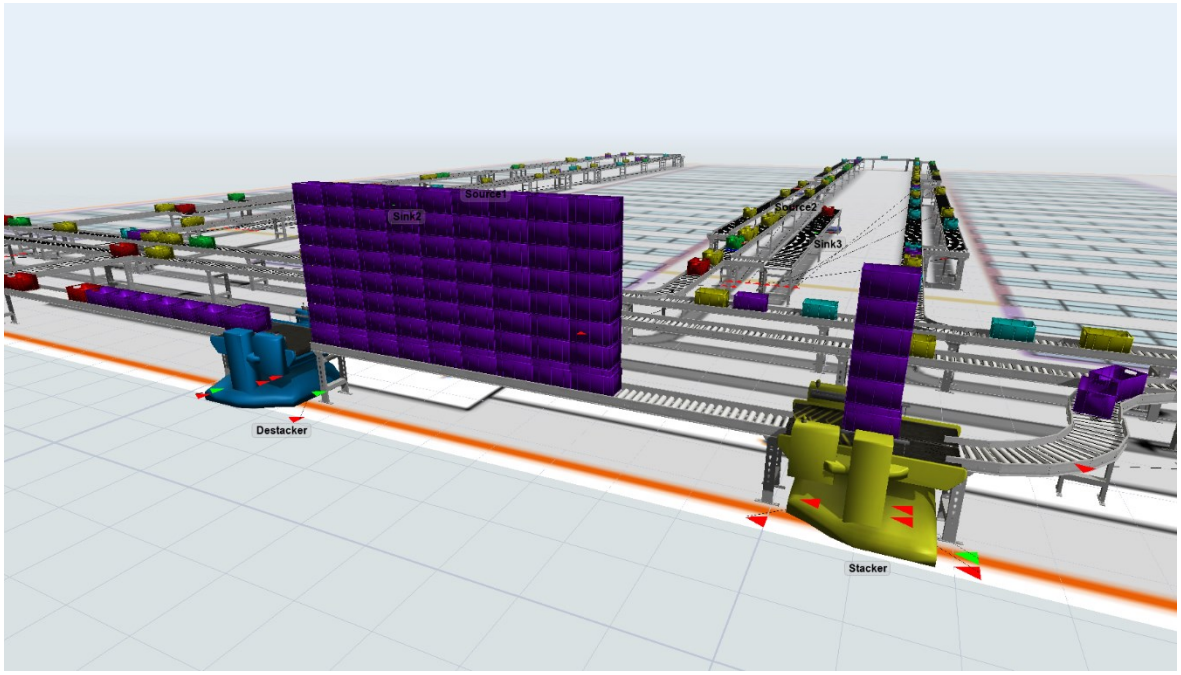

Figure 3. Stacking and destacking of the containers.

Source: Own study.

When human resources proved to be the bottleneck, the number of employees was increased to test the maximum efficiency of the installation. The study showed an increase in the efficiency of the decanting stations, as in the baseline model, the workstations had a maximum technical capacity of 480 containers per hour. Therefore, increasing the flow in the model prevented decanting from achieving the intended plan due to limited technical throughput. To increase efficiency, the station's cycle time was reduced to approximately 5 seconds. This reduction in cycle time eliminated the bottleneck. The refilling station was subjected to the same adjustment, as its cycle time depended primarily on the number of operators performing the process. To ensure continuous flow and eliminate the bottleneck resulting from the number of human resources, the cycle time was reduced from 15 seconds to 10 seconds.

7. Analysis of the capabilities of the base model and the improved model

In the experimental phase, the system's efficiency was examined for various takt times and process cycles. Two variants were examined:

- the number of containers with completed components that left the system during an hour, a shift, and a full day,
- the number of containers that were sent as replenishment to picking locations, also during an hour, a shift, and a full day.

To simplify the simulation model, it was assumed that there should always be a balance between picking and replenishment. This assumption eliminated unknown parameters and random factors that could distort the simulation results. The primary goal was to achieve repeatability, therefore, a single strategy was tested, balanced for both the baseline and improved models.

As part of the research, 72 measurements were performed, which were divided into two research phases. The first phase, in which 40 measurements were performed, was aimed at examining the base model, while 32 measurements were performed in relation to the already improved model. The smaller amount of measurement was due to the fact that the installation reached its maximum at the 32nd measurement, which was a significant improvement compared to the base model. The tests carried out showed that for non-accumulating conveyors, the maximum system efficiency at which 100% stability occurred was approximately 600 containers per hour, while with accumulating conveyors, the maximum technical efficiency was 1000 containers per hour (Figure 4).

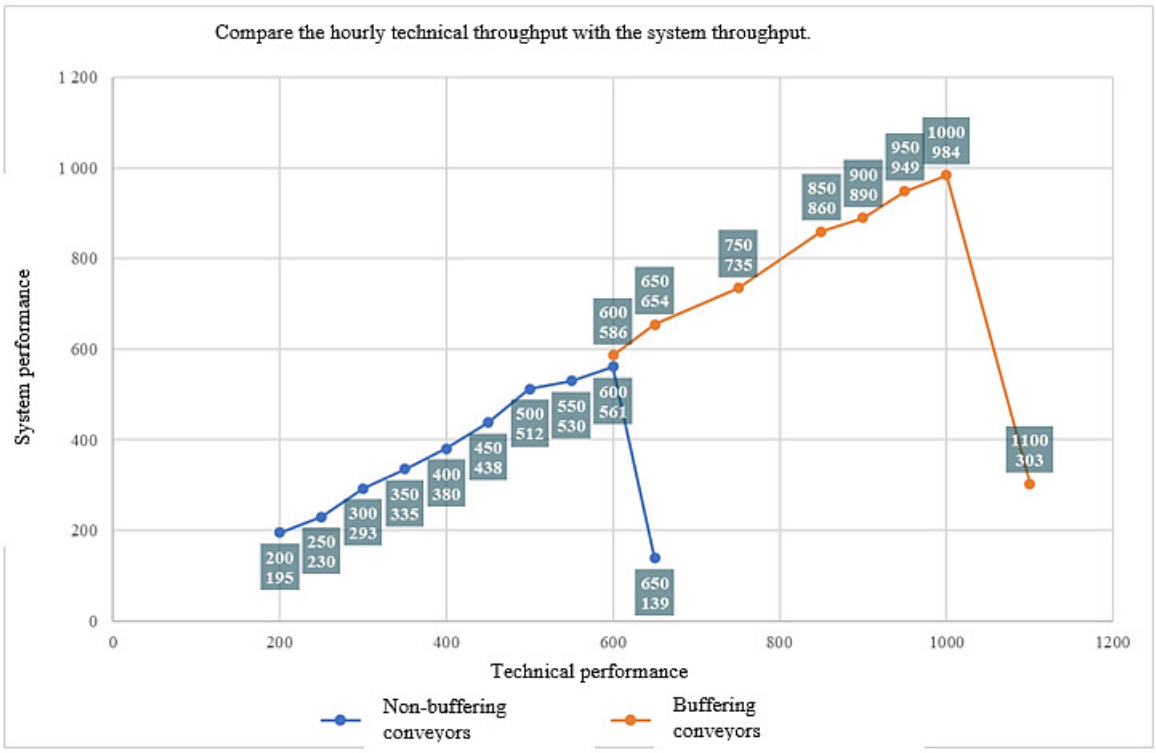

Figure 4. Comparison of system performance of research models (description in text).

Source: Own work.

8. Valuation of logistics systems

The investment required to build the baseline model is approximately €1.8 million. The costs listed in Table 1 include, among others, accumulating and non-accumulating conveyors, which are a crucial element of the logistics installation, as well as the IT system responsible for controlling the logistics process and directing the flow of containers on the conveyor. Auxiliary equipment, such as bends or transfers, which are used to redirect the flow of containers in the appropriate direction, was also estimated.

Table 1.
Valuation of the investment in the implementation of the base model

	Equipment type	Unit price	Quantity	Unit	Net price
1	Conveyors				1668675 €
1.1	Accumulation conveyor	2 500 €	385	Running meter	962 675 €
1.2	Non-accumulating conveyor	1 500 €	228	Running meter	342 000 €
1.3	Conveyor transfer	6 500 €	40	Piece	260 000 €
1.4	Conveyor bend	6 500 €	8	Piece	52 000 €
1.4	Conveyor bend	6 500 €	8	Piece	52 000 €
2	IT Warehouse Control System	120 000 €	1	System	120 000 €
Total installation cost					1 788 675 €

Source: Own study based on market analysis.

The improved simulation model incorporates accumulator conveyors into the system valuation instead of non-accumulator ones. Implementing the assumed improvements requires an investment of approximately €1.8 million for the conveyors alone, which is approximately €102,000 more than the baseline model. Other costs are presented in Table 2.

Table 2.
Investment valuation in the improved model

	Equipment type	Unit price	Quantity	Unit	Net price
1	Conveyors				1 771 000 €
1.1	Accumulation conveyor	2 500 €	568	Running meter	1 420 000 €
1.2	Conveyor transfer	6 500 €	40	Piece	260 000 €
1.3	Conveyor bend	6 500 €	14	Piece	91 000 €
2	Stacker and destacker				100 000 €
2.1	Stacker	50 000 €	1	Piece	50 000 €
2.2	Destacker	50 000 €	1	Piece	50 000 €
3	Dekantacja				65 000 €
3.1	Decanting station	5 800 €	10	Piece	58 000 €
3.2	Code scanner	700 €	10	Piece	7 000 €
4	IT Warehouse Control System	300 000 €	1	System	300 000 €
Total installation cost					2 236 000 €

Source: Own study based on market analysis.

In terms of CAPEX (Capital Expenditure), the improved model requires approximately €514,000 more investment. The percentage difference between the baseline and improved models is approximately 25%. The comparison takes into account, among other things, the "unexpected investments and costs" parameter, which in this type of project fluctuates

around 15%. An investment buffer has been added to the base amount to secure funds for design changes and to cover the potential costs of additional certificates or building permits.

9. Conclusions

As a result of the design work, a so-called baseline model of the transport conveyor network system was developed, which was to be purchased and implemented in the warehouse. The presented research demonstrated that using simulation tools, it was possible to create an improved baseline model and then compare these models in terms of performance and purchase costs. The research demonstrated that the improved logistics model is characterized by significantly higher technical efficiency, almost twice as high as the baseline model. In this study, the improvements yielded a positive result, improving the number of order containers fulfilled by approximately 67% and increasing the number of replenishments by nearly 75% compared to the baseline model. It should be noted that the improved transport conveyor network model did not significantly increase the warehouse space occupied.

The information obtained from the computer simulation is helpful in making decisions about the selection of a transport system, as it allows for weighing the benefits against the costs of the selected model. The research shows that the best solution is to implement an improved model, however, due to the additional investment outlays, which amount to approximately EUR 515,000 thousand, the company may decide to use the basic model and, as business needs increase, rebuild the installation.

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HOW TO OPERATIONALIZE STRATEGIC PROCUREMENT? CONTENT VALIDATION RESULTS

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Purpose: Recent years have been characterized by an increased number of strategic surprises, leading to supply chain disruptions, cost pressures, the need to develop sustainable practices, and the search for innovative solutions with suppliers. Due to these phenomena, a growing number of studies in the fields of operations and supply chain management examine purchasing in a strategic context. However, there is still a lack of studies that comprehensively address strategic procurement (SP), operationalizing in detail all its important dimensions, and supporting the development of a SP measurement scale. The limited number of previously proposed instruments to measure SP are one-dimensional constructs which present methodological challenges.
Design/methodology/approach: This study combines systematic literature reviews with content validation of the SP construct to propose an updated definition of the SP.
Findings: Within the scope of SP, four sub-processes were identified (innovation sourcing, cost optimisation, risk management and developing sustainability), each with 6 to 12 items. Expert-based panel supported the content validity of the SP measurement instrument, with three items indicating the need for revision or removal. Synthesizing these results with the findings from systematic literature reviews allowed for the formulation of an updated definition of SP.
Research limitations/implications: The proposed set of indicators can serve as a ready-made input for the next stage of scale development, i.e. construct validation.
Practical implications: Content validated sub-processes and items offer practitioners a roadmap toward SP.
Originality/value: This study provides a novel multidimensional construct as well as an updated definition of SP.
Keywords: strategic procurement, content validity, definition.
Category of the paper: Research paper.

1. Introduction

Purchasing is an essential aspect of managing modern companies and supply chains. Strategic surprises, such as the COVID-19 pandemic (Singh et al., 2021) or armed conficts (Halser, Paraschiv, 2022), combined with pressure to achieve cost savings (Ellram et al., 2020),

the need to implement ESG practices in supply chains (Walker, Brammer, 2009) and growing importance to enhance R&D processes with support of suppliers (Delgado-Verde, Díez-Vial, 2023) forcing purchasing professionals to seek for alternatives to those practices that cease to function (Öberg, 2022). Purchasing, therefore, needs to be taken on a strategic level that allows companies to safeguard their supplies and use opportunities coming from supply chains. The first step in understanding strategic procurement (SP) is to analyze its triggers. Designing a structured assessment instrument can facilitate this process (Kauppi, Luzzini, 2022). The development process involves four stages: stage 1 – instrument development, stage 2 – expert judgement, stage 3 – scale dimensionality and validation, and stage 4 – nomological validity. This study presents the first two stages of this process, enabling the development of a definition of the SP.

The classic definition of purchasing refers to acquiring materials in the right quantity and quality, delivering them to the right place, at the right time and at the right price (Lysons, Farrington, 2005). Another perspective emphasises supplier selection, placing an order and acquiring goods and services (Bodnar, Hopwood, 2004). These approaches focus on the fundamental elements of purchasing process. The modern and prominent definition considered by its author to be tactical, conceptualises purchasing as the management of a company's external resources. Supplies of the needs must be organised from suppliers on the most favourable terms (Van Weele, 2014). Definitions are not intended to explain the entire concept, but the fact is that the above leaves the potential user with a dilemma as to what terms are "right" or "most favourable" in practice.

Strategic purchasing is broadly defined in governmental services, particularly in healthcare (Smotritskaya, Shuvalov, 2017; Klasa et al., 2018; Greer et al., 2020). However, given that this study focuses on the market approach, the business perspective must be considered. From this point of view, purchasing is strategic when it is:

- linked to the company's goals and priorities (Johnsen et al., 2014),
- aligned with competitive organisational strategy (Rendon, 2005),
- successfully transferred into goals for buyers (Monczka et al., 2009).

To be strategic, purchasing function must be integrative, proactive, long term oriented, and consistent with the firm's goals (Carr, Pearson, 2002). Depending on the author, different aspects of strategic purchasing are emphasised. First, strategic purchasing decisions are seen as taking advantage of opportunities in the market, considering the firm's capabilities (Carr, Smeltzer, 1997). Sollish and Semanik (2011) focus on maximising the value of purchased goods and services by locating, qualifying, hiring, and developing suppliers through strategic sourcing. It is also worth noting the factor of effective management of the supply base to identify suppliers who could be partners for long-term collaboration (Talluri, Narasimhan, 2004). Accordingly, supply planning and contracting can be added to this catalogue (Schiele, 2019). Practitioners affiliated with the Chartered Institute of Procurement & Supply (CIPS) have their descriptive definition of SP, which focuses on negotiating, communicating,

and preserving long-term relationships with suppliers while reducing the supplier base (CIPS, 2012). It is important to emphasise that, among all other aspects, CIPS underlines environmental consciousness.

As seen in the definitions above, there is a lot of terminology in the literature and practice related to purchasing. Words such as purchasing, sourcing and procurement are used interchangeably in the same context. To clarify, procurement is broader than purchasing or sourcing (Lysons, Farrington, 2005). It includes all the procedures necessary to move a product from a supplier to where it will be used (Van Weele, 2014). Since some of the concepts in the study, such as work on improvement of internal processes or initiation of development projects in the company, do not even fall perfectly within this scope, a narrower option cannot be used. Therefore, for the purpose of this study, the term strategic procurement (SP) should be considered.

To effectively manage procurement strategically - with a long-term perspective and based on a system approach - an in-depth understanding of the phenomenon is required. It is necessary to establish a precise construct of the SP. However, there is a lack of a common scale, accounting for all its relevant dimensions, that can help measure and define the phenomenon. There have been few studies in the past where the SP variable has occurred, including one that used a structured scale development procedure (Chen, Paulraj, 2004; Chen et al., 2004). In all cases, it has been a unidimensional construct called either strategic purchasing (Carr, Pearson, 2002, 1999; Chen, Paulraj, 2004; Chen et al., 2004) or strategic sourcing (Su, Gargeya, 2012). Two of the scales mentioned are three-item scales (Carr, Pearson, 1999; Su, Gargeya, 2012), one is a four-item scale (Carr, Pearson, 2002), and the last is a seven-item scale (Chen, Paulraj, 2004; Chen et al., 2004).

From a scientific perspective, it is not easy to develop an evidence-based theory without using well-constructed and validated measurement instruments Heggestad et al., 2019). Therefore, there is value in developing a structured SP assessment instrument to define scope of the phenomenon that allows the design and implementation of successful purchasing management strategies in practice and help to define scope of interest. To achieve this, the instrument must be validated.

Validity means how well a scale measures a specific variable (DeVellis, 2017). The scale includes all elements of the measurement instrument (i.e., questionnaire items, response formats, and instructions for respondents) that affect the measurement process and the data obtained. Validity ensures that the measurement instrument measures precisely what it is supposed to measure (i.e., the theoretical concept, domain or variable that is the target of measurement, called the construct). It ensures that the instrument reflects that particular concept, domain, or variable, not some other phenomenon (Carmines, Zeller, 1979). Validity can be deduced from a scale's construction process, its capacity to predict particular outcomes, or its connections to measures of other constructs. These procedures correspond to three different types of validity: content, criterion-related, and construct (DeVellis, 2017).

Content validity is the degree to which elements of a measurement instrument are relevant to and representative of the targeted construct for a particular assessment (Cook, Beckman, 2006).

While the representativeness of a measurement instrument is the extent to which its elements are proportionate to the facets of the targeted construct, the relevancy of a measurement tool relates to the appropriateness of its elements for the targeted construct and the functions of assessment (Haynes et al., 1995). Of these two aspects of content validity, the relevancy of the measurement instrument is the most commonly used to measure content validity (Polit et al., 2007). In this regard, content validity is specifically the appropriateness of a sample of items—that is, how well a given set of items captures a particular content domain. Therefore, content validity plays a primary role in the measurement tool development process. It allows for catching potential errors in operationalising the construct at the initial stage of the scale development process to increase the chances of achieving the required instrument's construct validity at the final stage.

As shown in Table 1. Stage 1, i.e. instrument development, involves three steps: 1) identifying the content domain, 2) generating the item pool, and 3) constructing the instrument, including the measurement format (Zamanzadeh et al., 2014; DeVellis, 2017).

Table 1.
Stages and Steps Involved in Content Validity

Step	DeVellis (2017)	Zamanzadeh et al. (2014)	
1	Determine what it is you want to measure	Domain identification	Stage 1: Instrument development
2	Generate an item pool	Item generation	
3	Determine the format for measurement	Instrument formation	
4	Have the initial item pool reviewed by experts	- Relevancy of items. - Clarity of items. - Necessity of items. - Comprehensiveness of the instrument.	Stage 2: Expert judgement

Source: own study based on DeVillis (2017) and Zamanzadeh et al. (2014).

Assessment of the scale's content validity is conducted in Stage 2. It requires expert judgement, which is conducted in the form of a panel of experts whose task is to review the initial pool of items for relevancy, clarity, necessity and comprehensiveness (Zamanzadeh et al., 2014; DeVellis, 2017). Domain expertise, specialised training, or professional experience in the field must be considered when choosing panel members. Based on expert responses, the content validity of both the items and the entire measurement instrument is assessed. It is recommended that at least three and not more than 10 experts be engaged when judging content validity (Lynn, 1986). Although the maximum number of experts to be included in the process has not been established, using more than 10 experts is unlikely, because doing so decreases the chance of agreement (Lynn, 1986).

According to the two-stage approach shown in Table 2, this study aims to develop an SP measurement instrument and evaluate the content validity of the proposed dimensions. The SP construct was generated through interviews with 12 practitioners, a non-systematic and systematic literature review using grounded theory methodology and rewriting items in several stages. The content validity of the generated items was then assessed in collaboration with six experts in the field. Content validity was quantified using the content validity index (CVI) and the modified Kappa coefficient.

Table 2.
Steps in the study

Step number, according to DeVellis (2017) and Zamanzadeh et al. (2014)	Steps in the study	
1	- Interviews with 12 practitioners. - Non-systematic literature review.	Stage 1: Instrument development
	- Systematic literature review to find the results of earlier systematic literature reviews of strategic procurement. - Systematic literature review: Strategic procurement definition.	
2	Systematic literature review: strategic procurement elements. Item generation based on the grounded theory approach.	
3	Items rewritten three times.	
4	- Six semi-structured expert interviews. - Statistical analysis of results for relevancy and clarity (I-CVI, S-CVI, Kappa statistic). - Final formation of items (based on the results of the statistical analysis and the assessment of both the necessity of items and the comprehensiveness of the instrument).	Stage 2: Expert Judgement

Note: I-CVI = item content validity index; S-CVI = scale content validity index.

The procedure was designed to facilitate the identification of the key sub-processes and items of SP. The results obtained through the content validity assessment provided a broader understanding of the phenomenon and contributed to the expansion of its definition.

2. Stage 1: Instrument development

Step 1 involved domain identification through 12 open-ended interviews with practitioners. The results were coupled with a non-systematic literature review, particularly on the fundamental duties and obligations of purchasing (Van Weele, 2014). In the end, it was concluded that operational excellence, innovation sourcing, cost optimisation, risk management, and developing sustainability were five potential sub-processess of SP. These results provide a general overview of the concept but cannot be used directly in developing the construct. No research protocol was in place that makes decision-making in data acquisition and use arbitrary (Moher et al., 2015).

Aware of the shortcomings mentioned above, before beginning a systematic literature review for the domain under study, it was determined whether similar studies on SP had been conducted previously. Searches in Scopus, Ebsco, Google Scholar, and Emerald were made based on search string: ('literature review' OR 'review of the literature' OR 'overview' OR 'systematic review' OR 'meta-analysis') AND 'strategic' AND ('purchasing' OR 'procurement' OR 'sourcing' OR 'buying') for papers published in English between 2011 and 2021. Of the 10 articles identified, two contained a systematic protocol (Hong, Kwon, 2012; Zimmermann, Foerstl, 2014). Since both are outdated, there was a case for re-running the study.

Therefore, another systematic literature review was conducted to determine the meaning of SP. Based on the designed search string sounding: 'strategic' AND ('purchasing' OR 'procurement' OR 'sourcing' OR 'buying') AND ('definition' OR 'description' OR 'explanation'), papers published in English between 2011 and 2021 were identified through Scopus, Ebsco, Google Scholar, and Emerald academic databases. Furthermore, relevant definitions that did not emerge from the search process were manually added. A summary of the results is included in the introduction.

Step 2 involved generating the item pool. Following the procedures proposed by Booth et al. (2016) and Tranfield et al. (2003), a systematic literature review was conducted using the Scopus, Ebsco, Google Scholar, and Emerald databases. The search covered studies published in English between 2011 and 2021, employing the following keywords: 'strategic' AND ('purchasing' OR 'procurement' OR 'sourcing' OR 'buying') AND ('elements' OR 'functions' OR 'responsibilities' OR 'dimensions' OR 'practices' OR 'factors'). Where possible, the search was further refined to include only papers and knowledge bases related to economics, management, and business. With each additional restriction, the resulting titles were reviewed until 10 consecutive suggestions generated by the search engines yielded no results that could be considered relevant to the research topic**.** Based on this process, a table with selected publications was compiled. Within this table, 41 duplicate records were removed. Finally, a procedure to read the abstracts of 118 articles was performed to further decide on inclusion (Xiao, Watson, 2019) and their relevance to the research topic. A total of 65 studies were accepted for full-text review. Based on the information extracted from these papers, items were generated using the grounded theory approach, which proposes a structured methodology for data analysis. Several steps of text coding, including open coding, axial coding, and selective coding lead to a description of the theory (Heath, Cowley, 2004). In the end, in step 3, 34 items were subjected to a triple-rewriting procedure to provide the most straightforward and precise possible wording. Finally, the items were categorised into the potential SP dimensions identified in Table 3.

Table 3.
List of generated items

Item	Sub-processes	Item	Inspired by
1	Innovation sourcing	The purchasing department uses early supplier involvement in developing the company's products.	(Castaldi et al., 2011) (Van Poucke et al., 2016) (Luzzini et al., 2015) (Rajkumar, Stentoft, 2017) (Rodríguez-Escobar, González-Benito, 2017)
2	Innovation sourcing	The purchasing department searches for new technological solutions from suppliers.	(Castaldi et al., 2011) (Luzzini et al., 2015)
3	Innovation sourcing	The Purchasing Department selects suppliers whose expertise and capabilities can provide a competitive advantage for the company in the future.	(Homfeldt et al., 2017) (Jermsittiparsert, Rungsrisawat, 2019) Rajkumar, Stentoft, 2017)
4	Innovation sourcing	The purchasing department is committed to improving the company's internal processes.	(Castaldi et al., 2011)
5	Innovation sourcing	The purchasing department initiates development projects in the company.	(Rajkumar, Stentoft, 2017) (Castaldi et al., 2011)
6	Innovation sourcing	The purchasing department works with the sales and marketing departments to better understand customer expectations.	(Tunisini, Sebastiani, 2015)
7	Cost optimisation	The purchasing department controls the level of supplier diversification, buying a given product/raw material/service from a limited number of contractors.	(Hesping, Schiele, 2016) (Úbeda et al., 2015)
8	Cost optimisation	The purchasing department acquires technological knowledge to analyse the manufacturing cost structure for key raw materials/products/services before negotiations.	(Schütz et al., 2020)
9	Cost optimisation	The purchasing department seeks alternative suppliers to achieve negotiating leverage.	(Hesping, Schiele, 2016)
10	Cost optimisation	The purchasing department acquires knowledge about purchasing markets to intensify price competition among suppliers.	(Schütz et al., 2020) (Hesping, Schiele, 2016)
11	Cost optimisation	The purchasing department is gaining knowledge on how to conduct inquiries, negotiations and contracting to exploit advantages over suppliers better.	(Schütz et al., 2020)
12	Cost optimisation	The purchasing department controls the share of costs for which it is responsible concerning the total costs incurred by the company (spent under management).	(United States Government Accountability Office, 2012)
13	Cost optimisation	The purchasing department assists in the cost optimisation of processes within the company based on suppliers' experience.	(Schütz et al., 2020) (Hesping, Schiele, 2016) (Rodríguez-Escobar, González-Benito, 2017)
14	Cost optimisation	The purchasing department analyses purchase prices and the total cost of ownership (TCO) of the products/raw materials/services purchased.	(Hesping, Schiele, 2016) (Sharma, 2016) (Schütz et al., 2020) (Úbeda et al., 2015)
15	Cost optimisation	The purchasing department can give up the cheapest offer in favour of other values (e.g., better quality, reliability and supplier flexibility).	(Rodríguez-Escobar, González-Benito, 2017) (Sharma, 2016)
16	Cost optimisation	The purchasing department implements joint cost-saving projects with suppliers.	(Úbeda et al., 2015)
17	Cost optimisation	In selected areas, the purchasing department integrates suppliers IT-wise to hand over to them the supply and inventory management of products/raw materials (VMI - Vendor Managed Inventory).	(Yavas et al., 2011)

Cont. table 3.

18	Risk management	The purchasing department signs commercial contracts with key suppliers.	(Arney et al., 2014)
19	Risk management	The purchasing department identifies potential problems in cooperation with strategic suppliers and counteracts them before the situation becomes critical.	(Dixit, 2020) Gangurde, Chavan, 2016)
20	Risk management	The purchasing department has developed ways to act in the event of a spike in demand for purchased raw materials/products/services.	(Ila Manuj, 2013)
21	Risk management	The purchasing department has developed ways to act in the event of a spike on the supply side of the raw materials/products/services being purchased (e.g., through delays in supply chains).	(Ila Manuj, 2013)
22	Risk management	The purchasing department analyses the financial condition of suppliers (e.g., to avoid working with companies facing insolvency).	(Kotula et al., 2018)
23	Risk management	The purchasing department uses established non-price criteria for selecting suppliers.	(Nepal, Yadav, 2015) (Rodríguez-Escobar, González-Benito, 2017) (Raut, Bhasin, 2012)
24	Risk management	The purchasing department uses established criteria for the periodic evaluation of suppliers.	(Loppacher et al., 2011) (Raut, Bhasin, 2012) (Rodríguez-Escobar, González-Benito, 2017)
25	Risk management	The purchasing department is developing relationships with key suppliers for use in emergencies.	(Dixit, 2020) (Eltantawy et al., 2014) (Formentini et al., 2019) (Gangurde, Chavan, 2016)
26	Risk management	The purchasing department engages key suppliers in improving (e.g., diversifying) product/raw material/service logistics.	(Rodríguez-Escobar, González-Benito, 2017)
27	Risk management	The purchasing department works with suppliers to improve the quality of products/raw materials/services.	(Gangurde, Chavan, 2016) (Loppacher et al., 2011) (Huma et al., 2020)
28	Developing sustainability	When selecting suppliers, the purchasing department considers their environmental activities.	(Bag, 2016) (Timlon, 2011) (Tchokogué et al., 2018)
29	Developing sustainability	The purchasing department expects suppliers to intensify their environmental activities.	(Dabhilkar et al., 2016) (Tchokogué et al., 2018)
30	Developing sustainability	When planning supply chains, the purchasing department considers not only their costs but also the level of pollution generated.	(Sadeghi Rad, Nahavandi, 2018)
31	Developing sustainability	The purchasing department's green attitude lowers the company's carbon footprint.	(Schoenherr et al., 2014) (Tchokogué et al., 2018)
32	Developing sustainability	The purchasing department prefers suppliers demonstrating social responsibility activities (such as supporting employees or the local community).	(Flammer, 2018)
33	Developing sustainability	The purchasing department supports local suppliers and, thus, the region's development.	(Tchokogué et al., 2018)
34	Developing sustainability	By setting equal requirements for suppliers, the purchasing department promotes fair competition among them.	(Tchokogué et al., 2018)

Sub-processes can now be provided with explanations. In this respect, innovation sourcing in SP results from using new raw materials/products/services from suppliers or introducing new practices (e.g., the early involvement of suppliers in the product design process). Cost optimisation in SP comes from cost savings and negotiation (e.g., diversification of supply

sources). Risk management in SP is the response to potential supply disruptions, changes in production or customer demand (e.g., action plans for supply chain delays). Developing sustainability in SP involves environmental consciousness and social responsibility of the purchasing process (e.g., ensuring fair competition in purchasing markets or educating suppliers on environmental requirements).

Operational excellence in SP included only one article out of 65, making it clear that developments in information technology (IT) (including artificial intelligence), will free human focus from a large portion of operational topics to support other activities that still cannot be performed by computers (Bienhaus, Haddud, 2018). Future considerations of the purchasing education process explain the lack of academic interest in exploring this problem. Given the increasing levels of automation, are students better prepared for a future career in purchasing if they only learn the basics of purchase order processing from a textbook, or should they also engage in project-based learning that teaches them how to design processes while having an in-depth understanding of the role of IT (Bals et al., 2019). In practice, the most prominent enterprise resource planning (ERP) suppliers offer modules that enable the creation and dispatch of purchase orders without human intervention (e.g., Oracle's Advanced Supply Chain Planning). Thus, the problem of operational excellence evolving into one that will be addressed by IT managers through system configuration and software development, rather than by buyers.

For these reasons, and because operational excellence belongs primarily to operational procurement, it has not been included in the list of dimensions of the SP construct.

3. Stage 2: Expert judgement

Step 4 in Stage 2 of the scale construction process was conducted with the participation of six domain experts – procurement managers with extensive expertise and years of practice (Table 4). A panel of experts was asked to rate each instrument item in terms of relevancy, clarity, necessity, and comprehensiveness. The qualitative content validity technique was used to adopt the advice of domain experts regarding the use of grammar, acceptable and accurate word choice, appropriate word placement within items, and appropriate scoring (Safikhani et al., 2013). Also, the evaluation of the items' necessity and the instrument's comprehensiveness was based on a qualitative assessment. Experts were asked whether the items that made up the questionnaire for measuring SP covered all critical aspects or whether certain items were missing; if so, they were asked to identify them.

Table 4.
Characteristics of the Domain Experts Chosen for Evaluating Content Validity

Position	Work experience (years)	Experience in procurement (years)	Experience with a current company (years)
1. Purchasing Manager	26	18	>1
2. Deputy Purchasing Director	17	17	17
3. Purchasing Director EMEA – Logistics	13	13	2
4. Lead Buyer	22	21	20
5. Purchasing Director	20	14	20
6. Managing Director	28	20	1

The experts were also asked whether any items of the instrument should be removed. In the quantitative content validity method, a CVI and a modified Kappa coefficient were calculated to assess the relevancy and clarity of the instrument's items. The value of the CVI for relevancy was determined both at the item level (I-CVI) and at the scale level (S-CVI) (Polit, Beck, 2006).

3.1. Assessment of Content Validity – CVI

To evaluate the instrument's items, the experts used a 4-point ordinal rating scale, where for relevancy, 1 meant *not relevant*, 2 - *somewhat relevant*, 3 - *quite relevant*, 4 - *highly relevant*, and for clarity, 1 meant *unclear*, 2 - *somewhat unclear*, 3 - *quite clear*, 4 - *clear* (Zamanzadeh et al., 2014). A 4-point scale was applied to avoid having a middle score that was both neutral and ambiguous (Lynn, 1986). To calculate the CVI for the relevance and clarity of each item (I-CVI), the number of experts who rated the item as relevant or clear (score of 3 or 4) was divided by the number of all expert panellists. Thus, the I-CVI ranges between 0 and 1, representing the proportion of experts who agree that each item is relevant (Waltz, Bausell, 1981). It is recommended that, for six (as was the case in our study) or more judges, the I-CVIs should be not lower than 0.78 (Lynn, 1986). Researchers use I-CVI data to guide the editing, removal or replacement of items.

For relevancy, the CVI was also computed for the scale level (S-CVI). There are two approaches to calculating the S-CVI. The S-CVI computed according to the universal agreement calculation method (S-CVI/UA) is the proportion of total items on the scale that received a rating of 3 or 4 by all domain experts (Polit, Beck, 2006). The second approach to calculating the S-CVI is based on the averaging calculation method. This produces S-CVI/Ave defined as the average proportion of items rated as 3 or 4 across all the judges (Waltz et al., 2010). The first method is more conservative because it requires universal agreement among experts. The second method does not require it, and being more liberal, is preferred, especially with more experts on the validation panel (Polit, Beck, 2006). S-CVI/Ave is calculated using average I-CVI and places more emphasis on average item quality than on average expert performance. To calculate the index in the universal agreement approach, the number of items considered relevant by all experts (or the number of items with a CVI of 1) is divided by the

total number of items. In the average approach, the sum of the I-CVIs is divided by the total number of items (Polit et al., 2007). The acceptable cutoff for demonstrating content validity for S-CVI/UA and S-CVI/Ave is 0.8 (Lynn, 1986; Polit, Beck, 2006), while a value of 0.9 indicates a recommended excellent score (Waltz et al., 2010). Items that do not satisfy the required minimum indices are reassessed.

3.2. Assessment of Content Validity – Modified Kappa coefficient

Although researchers frequently employ the CVI to measure content validity, this index does not consider the risk of inflated values due to chance agreement. Therefore, to obtain more quantifiable results in evaluating the judgements of domain experts, the CVI is aided by the Kappa coefficient of agreement. The modified Kappa statistic is a consensus indicator of inter-rater agreement that accounts for chance agreement (Polit et al., 2007). It is a crucial addition to the CVI because it sheds light on the extent of agreement beyond chance. Because it eliminates any random chance agreement, the Kappa coefficient computation ensures better content validity comprehension (Zamanzadeh et al., 2014). Calculating the modified Kappa statistic first requires calculating the probability of chance agreement for each item; that is, $P_C = [N! / A! (N – A)!] \times 0.5^N$. In this formula, N represents the number of experts on the panel, and A represents the number of panellists who concur that the item is relevant. The Kappa statistic is then calculated using the following formula: $K = (\text{I-CVI} - P_C)/(1 - P_C)$. Under the Kappa evaluation criteria, scores above 0.74 are considered excellent, scores between 0.60 and 0.74 are good, and scores between 0.40 and 0.59 are fair (Cicchetti, Sparrow, 1981).

4. Results

Regarding relevancy (Table 5), the I-CVIs for most scale items obtained values between 0.83 and 1, reaching an acceptable cutoff level. Only two items recorded lower values: 0.67 (item 33) and 0.33 (item 17). Similarly, in the case of clarity (Table 6), most of the scale items obtained acceptable I-CVI values, ranging from 0.83 to 1. Only one item achieved a value of 0.67 for this index (item 8). The S-CVI/Ave for the sub-processes of innovation sourcing, cost optimisation, risk management and developing sustainability were 0.97, 0.92, 1.00, and 0.83, respectively, in terms of relevance, and 0.94, 0.89, 0.98, and 0.90, respectively, in terms of clarity. The S-CVI/Ave for the entire scale was 0.94 for relevancy and 0.93 for clarity, confirming the high content validity of the items for the construct of SP. Items that received an I-CVI of 0.67 or 0.33 showed a need for revision. Modified Kappa coefficients for most items ranged from 0.82 to 1 in both reliability and clarity ratings, achieving scores regarded as excellent. Two items (one for relevancy - item 33, and another for clarity - item 8)

received a negative value (-4.33), reflecting disagreement among evaluators about their inclusion in the SP construct and mandating their revision or removal.

Table 5.
Relevancy Ratings on the 34-Point Scale of Strategic Procurement by Six Experts

Item	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	No. of ratings of 3 or 4	I-CVI	P_C	Kappa statistic
1	V	V	V	V	V	V	6	1.00	0.02	1.00
2	V	V	V	V	V	V	6	1.00	0.02	1.00
3	V	V	V	V	V	V	6	1.00	0.02	1.00
4	V	V	V	-	V	V	5	0.83	0.09	0.82
5	V	V	V	V	V	V	6	1.00	0.02	1.00
6	V	V	V	V	V	V	6	1.00	0.02	1.00
7	V	V	V	-	V	V	5	0.83	0.09	0.82
8	V	V	V	V	V	V	6	1.00	0.02	1.00
9	V	V	V	V	V	V	6	1.00	0.02	1.00
10	V	V	V	V	V	V	6	1.00	0.02	1.00
11	V	V	V	V	V	V	6	1.00	0.02	1.00
12	V	V	V	V	V	V	6	1.00	0.02	1.00
13	V	V	V	V	V	V	6	1.00	0.02	1.00
14	V	V	V	V	V	V	6	1.00	0.02	1.00
15	V	V	V	V	V	V	6	1.00	0.02	1.00
16	V	V	V	V	V	V	6	1.00	0.02	1.00
17	V	-	-	-	-	V	2	0.33	135.00	1.00
18	V	V	V	V	V	V	6	1.00	0.02	1.00
19	V	V	V	V	V	V	6	1.00	0.02	1.00
20	V	V	V	V	V	V	6	1.00	0.02	1.00
21	V	V	V	V	V	V	6	1.00	0.02	1.00
22	V	V	V	V	V	V	6	1.00	0.02	1.00
23	V	V	V	V	V	V	6	1.00	0.02	1.00
24	V	V	V	V	V	V	6	1.00	0.02	1.00
25	V	V	V	V	V	V	6	1.00	0.02	1.00
26	V	V	V	V	V	V	6	1.00	0.02	1.00
27	V	V	V	V	V	V	6	1.00	0.02	1.00
28	V	V	V	V	V	-	5	0.83	0.09	0.82
29	V	V	V	V	V	V	6	1.00	0.02	1.00
30	V	V	V	V	V	-	5	0.83	0.09	0.82
31	V	V	V	V	V	-	5	0.83	0.09	0.82
32	V	V	V	V	V	-	5	0.83	0.09	0.82
33	V	V	V	-	V	-	4	0.67	0.94	- 4.33
34	V	V	V	V	V	-	5	0.83	0.09	0.82

Note: S-CVI/Ave = 0.936 (accepted). I-CVI = item content validity index; Pc = probability of chance agreement; S-CVI = scale content validity index.

Table 6.
Clarity Ratings on the 34-Point Scale of Strategic Procurement by Six Experts

Item	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	No. of ratings of 3 or 4	I-CVI	P_C	Kappa statistic
1	V	V	V	V	V	V	6	1.00	0.02	1.00
2	V	V	V	V	V	V	6	1.00	0.02	1.00
3	V	V	V	V	V	V	6	1.00	0.02	1.00
4	V	V	-	V	V	V	5	0.83	0.09	0.82
5	V	V	-	V	V	V	5	0.83	0.09	0,.82
6	V	V	V	V	V	V	6	1.00	0.02	1.00
7	V	V	V	V	-	V	5	0.83	0.09	0.82
8	V	-	V	V	-	V	4	0.67	0.94	- 4.33
9	V	V	V	V	V	V	6	1.00	0.02	1.00
10	V	V	V	V	V	V	6	1.00	0.02	1.00
11	V	V	V	V	V	V	6	1.00	0.02	1.00
12	V	-	V	V	V	V	5	0.83	0.09	0.82
13	V	V	V	V	V	V	6	1.00	0.02	1.00
14	-	V	V	V	V	V	5	0.83	0.09	0.82
15	V	V	-	V	V	V	5	0.83	0.09	0.82
16	V	V	V	V	V	V	6	1.00	0.02	1.00
17	V	V	-	V	V	V	5	0.83	0.09	0.82
18	V	V	V	V	V	V	6	1.00	0.02	1.00
19	V	V	V	V	V	V	6	1.00	0.02	1.00
20	V	V	V	V	V	V	6	1.00	0.02	1.00
21	V	V	V	V	V	V	6	1.00	0.02	1.00
22	V	-	V	V	V	V	5	0.83	0.09	0.82
23	V	V	V	V	V	V	6	1.00	0.02	1.00
24	V	V	V	V	V	V	6	1.00	0.02	1.00
25	V	V	V	V	V	V	6	1.00	0.02	1.00
26	V	V	V	V	V	V	6	1.00	0.02	1.00
27	V	V	V	V	V	V	6	1.00	0.02	1.00
28	V	V	-	V	V	V	5	0.83	0.09	0.82
29	V	V	-	V	V	V	5	0.83	0.09	0.82
30	V	V	V	V	V	V	6	1.00	0.02	1.00
31	V	V	-	V	V	V	5	0.83	0.09	0.82
32	V	V	V	V	V	V	6	1.00	0.02	1.00
33	V	V	-	V	V	V	5	0.83	0.09	0.82
34	V	V	V	V	V	V	6	1.00	0.02	1.00

Note: S-CVI/Ave = 0.931 (accepted). I-CVI = item content validity index; Pc = probability of chance agreement; S-CVI = scale content validity index.

As for the results of the qualitative assessment of the necessity of the items and the comprehensiveness of the instrument, two of the six domain experts participating in the panel identified one additional item they felt was missing from the SP construct. One completed risk management sub-process read as follows: *The purchasing department analyses information on the level of complaints reported to suppliers to avoid serious quality problems*. The other, which read: *The purchasing department eliminates activities that do not add value to the purchasing process* was added to the cost optimisation sub-process. This increased the construct by two items, bringing the item pool to 36.

Based on the findings of the research, an attempt to develop an updated definition of strategic procurement could be made. This requires combining previous definitions with the findings from the development of the measurement instrument, resulting in the following definition:

> *The contribution to achieving a company's objectives (Johnsen et al., 2014), aligned with organisational strategy (Rendon, 2005), by managing external resources (Van Weele, 2014) to acquire products and services while maximising value (Sollish, Semanik, 2011) through cost optimisation and risk mitigation, with consideration given to innovativeness and sustainability.*

On top of that tables 5 and 6 gives detailed range of directions in each sub-process that can be taken to achieve practical success in practical implementation of SP.

5. Discussion

This study attempts to conceptualise the essence of SP by focusing on its triggers and causes, and to develop an instrument for its measurement. Linking abstract concepts to empirical indicators is a critical component of measuring. For a construct to be operationalised, it must be founded on items from a specific content domain appropriate for the given measuring circumstance. This is what content validity assures. Therefore, the proposed SP assessment instrument's content validity is influenced by a thorough literature review, solid theoretical base, and evaluation that reflects specialised subject-matter experience. The validation process was a two-stage process. In the instrument development stage, interviews with 12 practitioners and a non-systematic and systematic literature review based on the grounded theory method generated a pool of 34 items. Six domain experts were then asked to score the items in the judgment stage based on their necessity, clarity and relevancy. Through quantification of content validity based on CVI (I-CVI and S-CVI) and Kappa statistics, high content validity was revealed for 31 items, with three items indicating the need for revision or deletion. A qualitative assessment of the items' necessity and the instrument's comprehensiveness by domain experts resulted in the expansion of the SP construct by two additional items, thereby increasing the item pool to 36. Since the content domain was well defined, the construct's content validity computation reduced the discrepancy between academic and industry perspectives on strategic procurement. This does not alter the requirement that the proposed assessment tool thoroughly evaluate its psychometric qualities.

Previous research projects aimed at identifying the items of SP (Carr, Pearson, 1999, 2002; Chen, Paulraj, 2004; Chen et al., 2004; Su, Gargeya, 2012) describe significant but selected elements of the domain. Research that addresses SP comprehensively, without omitting any critical dimensions, is unknown to the author. By defining SP as a distinct construct with four

sub-processes - innovation sourcing, cost optimisation, risk management, and developing sustainability - the author of this paper provides a broader explanation of the phenomenon. To support understanding and usability of the findings each sub-process is described with a set of six to twelve items.

The findings of the research project made it possible to combine earlier definitions of SP with the results of measurement instrument development, thereby. Based on that a broad and updated definition of the phenomenon was formulated. In this way, the author contributes to theory building. In addition, the definition is extended by a set of items for each sub-process of SP, which can be used to develop purchasing organisations towards a strategic level and used as measurement instrument by researchers.

The proposed construct was evaluated for content validity, which provided the basis for developing the definition of SP. However, it should be underlined that a fully developed measurement instrument requires additional validation steps. These include assessment of construct validity through exploratory and confirmatory analyses, criterion validity to verify whether the results are consistent with an external criterion sometimes (often referred to as a "gold standard"), and nomological validity to examine how existing construct corresponds with other related constructs. Establishing additional three forms of validity provide solid base to examine the influence of SP on other constructs, such as purchasing department performance and overall firm performance.

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ESG AND PROFITABILITY IN THE EUROPEAN BANKING SECTOR: A LITERATURE REVIEW

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Purpose: The aim of this paper is to examine the relationship between environmental, social, and governance (ESG) factors and the profitability of banks in the European banking sector, with a particular focus on identifying the main research trends.
Design/methodology/approach: The study is based on a systematic literature review conducted in accordance with selected PRISMA guidelines. The analysis includes peer-reviewed articles retrieved from the Web of Science and Scopus databases using predefined search queries applied to titles, abstracts, and keywords between years 2020-2026.
Findings: The results reveal no clear consensus regarding the impact of ESG on bank profitability. While some studies indicate a negative short-term relationship due to increased operational and investment costs, others highlight long-term benefits such as improved financial stability, reduced risk, and enhanced resilience. The findings also show that the effects differ across ESG dimensions and depend on methodological approaches, including the choice of variables and econometric models.
Research limitations/implications: The study is limited by its reliance on secondary data, focus on the European banking sector, and the heterogeneity of ESG measurement across studies. Future research should aim to standardize ESG indicators, explore causal relationships, and extend the analysis to other regions and banking systems.
Practical implications: The findings suggest that bank managers and policymakers should adopt a long-term perspective when implementing ESG strategies, taking into account both potential short-term costs and long-term benefits related to stability and risk reduction.
Social implications: The study highlights the importance of ESG practices in promoting sustainable development, improving transparency, and strengthening stakeholder trust in the banking sector.
Originality/value: This paper contributes to the literature by providing a comprehensive and up-to-date synthesis of research on ESG and bank profitability in Europe, identifying key research streams, methodological differences, and directions for future studies.
Keywords: ESG, profitability, ROE/ROA, banking sector.
Category of the paper: Literature review.

1. Introduction

The growing importance of environmental, social, and corporate governance (ESG) factors is one of the key trends in today's financial sector. In particular, the banking sector, as a vital component of the economic system, plays a fundamental role in capital allocation and in supporting the transition toward sustainable development. Although banks have not traditionally been viewed as environmentally harmful, they have increasingly engaged in environmental, social, and governance (ESG) activities (Matuszak-Flejszman et al., 2024). The integration of sustainability into banking dates back to the 1990s, when institutions began incorporating environmental considerations into their operations and financial products (Jeucken, 2010; Scholtens, 2009). Prior to the 2008 financial crisis, however, banks showed limited involvement in corporate social responsibility and sustainability reporting. The crisis marked a turning point, forcing banks to restructure their business models, reduce costs, and rebuild trust and reputation (Matuszak-Flejszman et al., 2024). As a result, many institutions intensified their engagement in sustainable and socially responsible activities. The expansion of non-financial disclosures has since been driven by growing stakeholder expectations and regulatory pressure for transparency.

There is growing interest in the relationship between ESG factors and the financial performance of banks and various financial sector institutions. Existing empirical research on the relationship between ESG and the financial performance of banks has yielded mixed results. On the one hand, it is suggested that implementing ESG practices may generate additional operating and investment costs, which in the short term may negatively impact profitability metrics such as return on assets (Jílková et al., 2025). On the other hand, the literature highlights the potential long-term benefits of sustainability initiatives, including improved reputation, risk mitigation, and increased financial stability for banks (Chiaramonte et al., 2022; Izcan, Bektas, 2022; Tóth et al., 2021). This points to the complex and multidimensional nature of the relationship under analysis.

Furthermore, research indicates that individual ESG pillars may affect financial performance in different ways, and factors such as corporate governance structure, market maturity, and the regulatory environment may modify the observed relationships. For this reason, the European banking sector, given its high level of regulation and the rapidly evolving landscape of sustainable finance policy, represents an interesting and still under-explored field.

Accordingly, the aim of this article is to fill this gap by conducting a literature review on the impact of ESG factors on bank profitability in the European banking sector. The study will involve a systematic analysis of available academic publications, focusing on identifying the main research trends and the relationships between ESG-shaping factors, with particular emphasis on profitability indicators. Thus, the article aims not only to organize existing knowledge but also to identify areas requiring further empirical research.

2. Methods

A systematic literature review was conducted to examine the prevalence of research investigation the profitability of European banks from an ESG perspective. The literature review was conducted according to selected PRISMA guidelines. The analysis was based on three areas: identification, screening, and eligibility. However, it should be mentioned that the exact number of records excluded from the analysis was presented globally both in terms of screening and eligibility assessment. Moreover, during the literature review process no new studies have been included after screening phase. What is more, the study was not registered in PRISMA registry. It can therefore be considered a partial systematic review. The literature review was based on Web of Science and Scopus databases according to abstracts, titles and keywords. The literature search was done on 9th April 2026.

The search strategy involved searching for articles using a combination of the terms "ESG" and "profitability" is presented in Table 1.

Table 1.
Search strategy

Item	Search strategy
Scopus	TITLE-ABS-KEY((ESG OR "environmental social governance")AND (bank* OR "financial institution*" OR "banking sector" OR "commercial bank*")AND (profitability OR performance OR "financial performance" OR "bank performance" OR ROA OR "return on assets"))
Web of Science	TS=(("ESG" OR "environmental social governance")AND ("bank" OR "financial institution" OR "banking sector" OR "commercial bank")AND TS= ("profitability" OR "performance" OR "financial performance" OR "bank performance" OR "ROA" OR "return on assets"))

Source: own elaboration.

A detailed overview of the study is shown in the flow diagram presented in Figure 1. The literature search was done on the basis of the following exclusive criteria:

- Time span: 2020-2026.
- Language: English.
- Document type: article.
- Publication stage: final.
- Source type: journal.
- Country: Europe.
- Opena access: All open access.

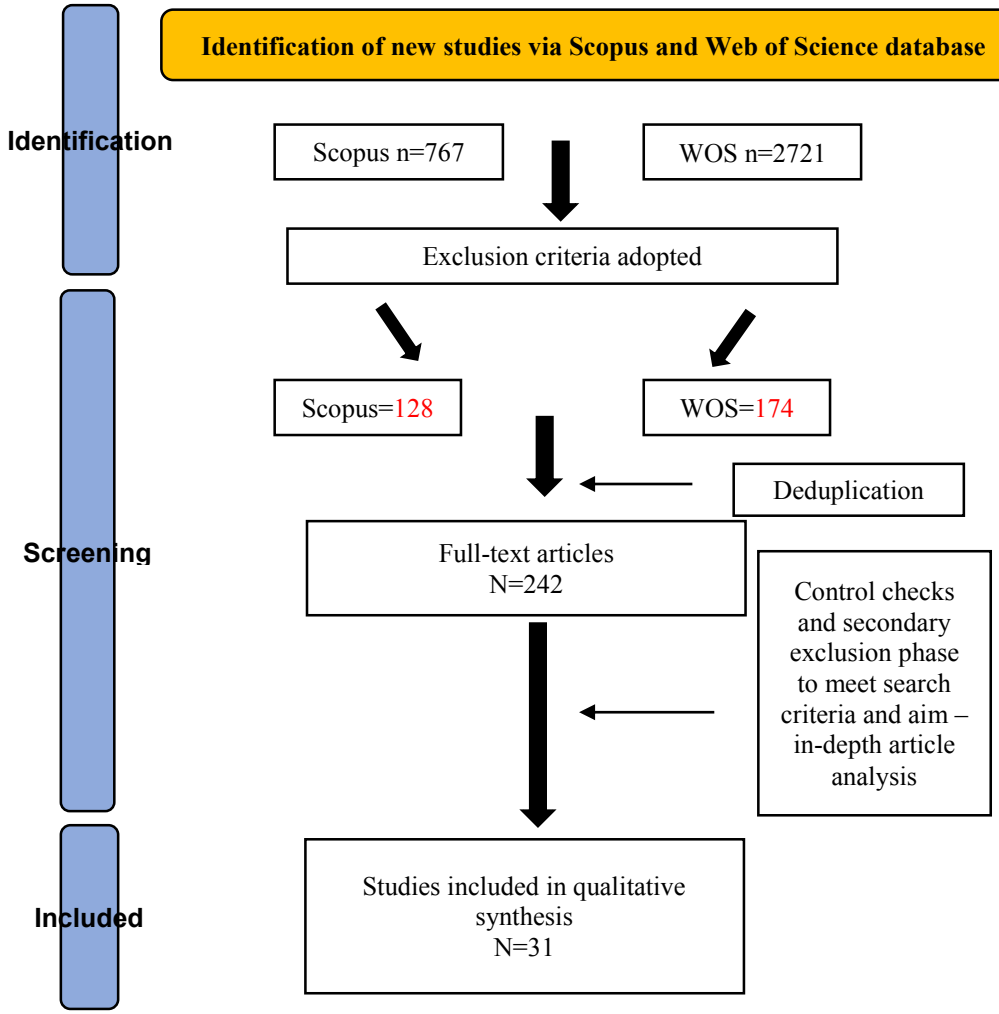

Figure 1. Flow diagram of search strategy.

Source: based on (PRISMA, 2026).

3. Results

The conducted literature review clearly indicates a significant increase in interest in the topic of bank profitability in the context of ESG since 2020. Most of the studies analyzed were conducted on a pan-European sample. Only a few studies focused on individual countries, i.e., Poland (Klimontowicz et al., 2021; Matuszak-Flejszman et al., 2024), Italy (D'Apolito et al., 2023; Menicucci, Paolucci, 2022, 2023), Romania (Nitescu, Cristea, 2020; Tóth et al., 2021), Turkey (Kaya, Ertuğrul, 2025) and UK (Giannopoulos et al., 2024).

The vast majority of studies focused on general issues related to examining the relationship between ESG and bank profitability (as many as 49% of the studies). In contrast, less than 20% of the studies addressed risk-related aspects: risk management (Del Sarto, 2025; Mandas et al., 2024; Manta et al., 2025; Nitescu, Cristea, 2020), climate related risk (Jiang et al., 2025; Paolone et al., 2024) or idiosyncratic risk (Izcan, Bektas, 2022). Figure 2 presents the details.

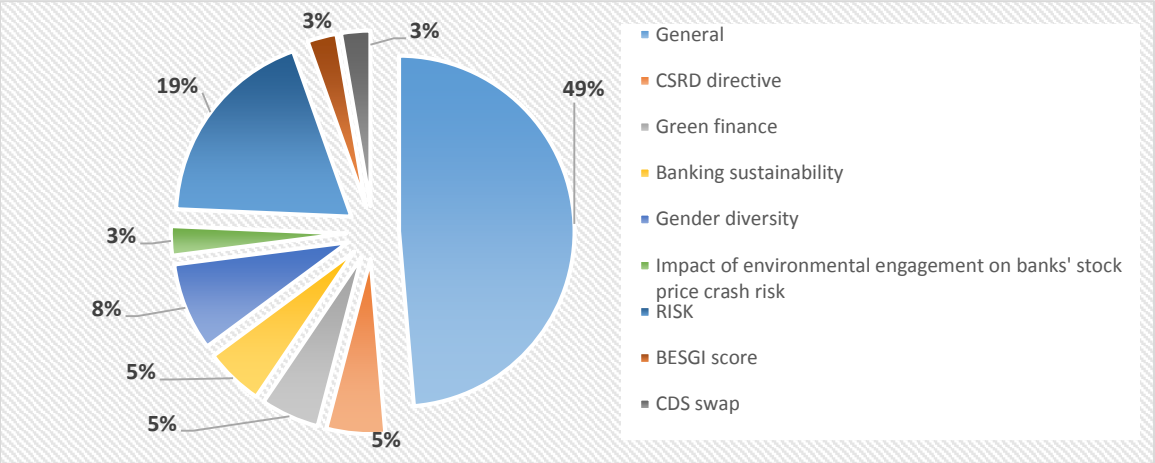

Figure 2. Research topics.

Source: own elaboration.

Upon analyzing the collected articles from the perspective of recurring keywords, it was noted that, in addition to ESG, the terms "financial performance" and "corporate social responsibility" appeared with equal frequency. Figure 3. illustrates the details of these relationships.

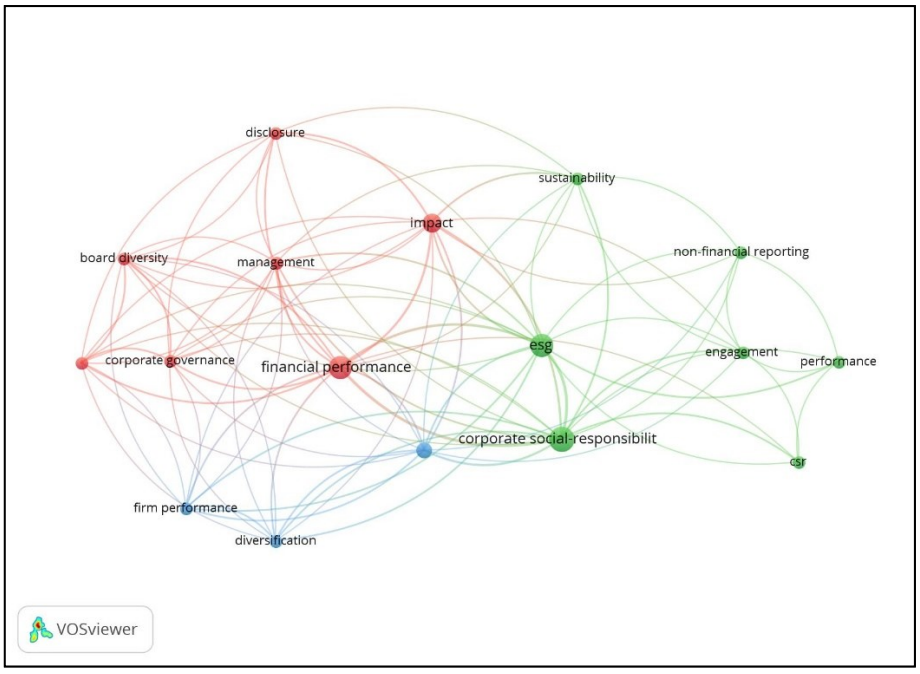

Figure 3. Research keywords.

Source: own elaboration in VOSviewer.

As part of the study, a summary of the objectives and conclusions from each article was also compiled. The details are presented in Table 2.

Table 2.
Research aims and results of analyzed articles

No.	RESEARCH AIM	AUTHOR/AOTHORS	RESULTS
1	Analysis of board of directors (BoD) and the environmental, social and governance (ESG) performance of 105 Italian banks during the period 2017-2021.	(Menicucci, Paolucci, 2022)	The main empirical results reveal that the board size, board independence and the presence of a CSR/sustainability committee **positively influence** a bank's ESG performance. No significant relationship between board average age and ESG performance is found. The relationship between gender-balanced boards and ESG performance is **positive.**
2	The influence of 6 distinct types of institutional investor on the ESG performance of companies.	(Giordino et al., 2026)	A **positive association** between a long-term institutional ownership structure and a company's ESG performance. Short-term oriented institutional investors exhibit a **negative correlation** with ESG performance.
3	The impact of ESG performance on the profitability of 192 European listed banks over the period 2009-2019	(Conca et al., 2025)	Environmental practices deliver more immediate benefits. Governance practices are vital for ensuring stability, they do not appear to be sufficient to drive short-term variations in profitability. Social practices are **negatively related** to profitability.
4	The potential bidirectional linkage between reputational risk exposure associated with ESG factors and market valuation.	(Mandas et al., 2024)	An **inverse bidirectional** causality between ESG reputational risk exposure and banks' market valuation. The impact of ESG reputational risk shocks on market valuation is more significant for high-exposed banks.
5	The dynamics between Corporate Social Responsibility (CSR), quantified through ESG scores, and financial performance	(Giannopoulos et al., 2024)	A **negative correlation** between the ESG score and both the ROA and ROE -> elevated CSR commitments may inversely impact short-term financial returns.
6	Banks' preparation for the new reporting rules based on the latest ESG reports	(Matuszak-Flejszman et al., 2024)	European banks, especially in Poland, are committed to integrating environmental and social issues into their business practices. **However there are identified significant gaps in the preparation** of polish banks **for non-financial reporting**.
7	The relationship between bank risk profile and ESG disclosure score	(Manta et al., 2025)	A positive relationship between bank risk and ESG disclosure score.
8	Banks' environmental engagement vs. future stock price crash risk	(Fiordelisi et al., 2023)	A negative relationship has been observed.
9	Which factors, including ESG factors, impacted the decline of book-to-market ratio	(Markoulis et al., 2025)	Return on equity and volatility of stock returns are important determinants of bank valuation.
10	How ESG controversies impact bank risk? How corporate governance can mitigate these risks?	(Del Sarto, 2025)	Strong governance structures, characterized by board diversity and independence, are found to mitigate the financial risks associated with ESG controversies, whereas weak governance amplifies these risks
11	The impact of board diversity on bank performance	(Aureli et al., 2026)	The board diversity **contributes positively** to performance. ESG investments **adversely affect** profitability ratios, but a more diverse board mitigates the possible detrimental effects of ESG expenses on company returns.
12	The asymmetric effects of climate-related actions on the profitability of European banks	(Jiang et al., 2025)	**Positive changes** in both country-level and bank-level climate actions enhance profitability in the long run.

Cont. table 2.

13	The joint and separate effects of Environmental (E), Social (S),and Governance (G) scores on bank stability	(Chiaramonte et al., 2022)	The total ESG score reduces bank fragility during periods of financial distress. This stabilizing effect holds strongly for banks with higher ESG ratings.
145	The relationship between corporate social responsibility and the idiosyncratic risk of Eurozone banks	(Izcan, Bektas, 2022)	**Negative relationship** between the overall ESG scores and the idiosyncratic risk of banks for medium- to high-risk levels. The effect becomes stronger as the riskiness of the banks increases.
15	The impact of environmental, social and governance (ESG) factors on Romanian banks and the opportunity to implement them in their own risk management strategies.	(Nitescu, Cristea, 2020)	As the return on assets or the leverage multiplier increases, the probability that the bank implements a risk management strategy associated with environmental, social and governance factors decreases, and the number of members of the management body positively impacts the decision to get involved in social responsibility activities.
16	The correlation between a series of indicators that measure the performance of ESG and the financial performance of banks.	(Bunea et al., 2025)	A **negative correlation** between the return on assets (ROA) and the governance score (G), as well as a **positive influence** of the ESG score on the return on equity (ROE).
17	Creation of new score – BESGI score	(Ielasi et al., 2023)	Compared to other more traditional ESG scores, the model: a) is bank-specific, b) is based on public data and then highly replicable, c) it can assess the level of a bank's sustainability both in its internal processes and procedures and in its choices about financing and investing activities, and d) is based on an innovative aggregation methodology, the Multidimensional Synthesis of Indicators, to consider the synergies among dimensions and penalize heterogeneity in the multidimensional bank results.
18	The effects of board cultural diversity (BCD) and board gender diversity (BGD) of the board of directors on environmental, social and governance (ESG) performance in the European banking sector.	(Paolone et al., 2024)	The **positive linkages** between BGD, BCD and ESG scores in the European banking sector. Moreover, the diversity contributes to knowledge sharing by improving ESG performance in a regulated sector. The combined effect of BGD and BCD **negatively impacts** ESG performance.
19	The relationship between financial stability and ESG performance	(Tóth et al., 2021)	ESG performance reduced the ratio of non-performing loans significantly. The **positive effect** of regulatory capital has been confirmed.
20	Verify (i) whether financial intermediaries adopt policies and make efforts to reduce the environmental impact of their operations; (ii) the observable trend in the environmental performance of the examined companies and (iii) the existence of a relationship between the environmental performance and the characteristics of the examined companies	(D'Apolito et al., 2023)	An increasing trend in the environmental performance of the examined intermediaries and a wide dissemination of policies aimed at reducing their impact on the environment. Environmental performance is significantly related to company size.
21	The role of ESG materiality in firm value, based on a sample of banks operating in OECD countries	(Aras & Hacioglu Kazak, 2022)	ESG performance based on ESG materiality has a **positive influence** on the firm value for both models, price-to-book value ratio (PBV), and Tobin's Q (TQ).

Cont. table 2.

22	The influence of economic support measures on banking profitability as measured by the ROA.	(Blaga et al., 2024)	The **negative impact** of economic support measures on bank profitability, especially for banks associated with the lower and middle quantiles of the distribution of the ROA.
23	The relationship between bank-specific environmental, social, and governance (ESG) performance and credit risk in the European Union	(Porenta et al., 2026)	**No significant relationship** is found for non-EA banks, and in some emerging-market cases, a reverse dynamic suggests a potential trade-off aligned with shareholder theory.
24	The relationship between sustainability and the financial performance of European banks, focusing on their Return on Average Assets (ROAA) and Return on Average Equity (ROAE).	(Jílková et al., 2025)	A **negative correlation** between sustainability factors and short-term profitability. A **potential association** between sustainability engagement and long-term financial resilience, though the exact causal mechanisms remain subject to further re-search.
25	The effect of Environmental, Social and Governance (ESG) scores and Credit Default Swap (CDS) spreads on the profitability of Halkbank	(Kaya, Ertuğrul, 2025)	ESG scores and CDS spreads **negatively affect** bank profitability
26	The relationship between board gender equality and environmental, social and governance (ESG) performance in the European banking sector.	(Menicucci, Paolucci, 2024)	A **significant positive relationship** between the number of women on BoD and the ESG performance of European banks only up to a certain threshold of female directors (at least three women).
27	The existence of a possible significant relationship between social disclosure and financial performance in banking institutions.	(Manta et al., 2020)	Our study provides empirical evidence that while there is a lack of efficiency and performance when boards are fragmented, the enactments of equal opportunity policies create a good reputation for the firm and the positive performance of staff.
28	The impact of environmental performance, social responsibility and corporate governance (ESG) on bank performance (BP).	(Menicucci, Paolucci, 2023)	ESG policies **negatively affect** operational and market performance in the banking sector. However, the relationships between ESG dimensions are mixed if measured individually. The results show a **significant positive impact** of emission and waste reductions on financial and operating performance, but regarding social aspects, it is proved that better product responsibility decreases accounting performance.
29	The relationship between ESGP and CFP (corporate financial performance) considering different dimensions of financial performance at once, both accounted-based (ROA and ROE) and market-based (Capitalisationto Book Value, Tobin's Q).	(La Torre et al., 2021)	The current approach of banking authorities, focusing on bank ESG risks, more than ESG opportunities, in order to "force" banks into adopting anew ESG business model, at this early stage of transition to sustainability
30	The impacts of board size, gender diversity and independence on ESG performance whilst also examining the impact of country-level social trust on such performance.	(Miranda et al., 2023)	ESG performance is **positively associated** with board gender diversity and independence and negatively associated with board size. Surprisingly, we find a negative relationship between country-level social trust and ESG performance.

Cont. table 2.

31	The impact of the ESC directive on banks' energy behavior disclosures, explicitly relating to behaviors towards energy use and its impact on banks' performance	(Klimontowicz et al., 2021)	Banks that are more likely to demonstrate energy behaviors (with a high BEB index) are those that better manage their costs and are more attractive for investors. Banks' energy behavior has no statistically significant correlation with other performance indicators.

Source: own elaboration. Discussion.

The analyses presented in the collected articles highlight the immense importance of environmental, social, and corporate governance (ESG) issues for commercial banks. In recent years, growing interest among policymakers, stakeholders, and researchers in corporate sustainability goals has contributed to the significant development and widespread use of ESG indicators (Blaga et al., 2024). This is reflected in the annually increasing number of academic articles published on this topic. European banks are committed to integrating environmental and social issues into their business practices, as (Matuszak-Flejszman et al., 2024) emphasized in her article. Importantly, they are increasingly exposed to ESG-related controversies situations in which their operations and/or products have a negative impact on the environment, society, or corporate governance (Blaga et al., 2024). Consequently, ESG analyses conducted within the banking sector cover a wide spectrum of diverse aspects: risk, green finance, and gender diversity.

The literature review indicates that the vast majority of studies focus on fairly holistic analyses of the relationship between ESG indicators and bank profitability. Issues related to risk, in particular risk management (Del Sarto, 2025; Mandas et al., 2024; Manta et al., 2025; Nitescu, Cristea, 2020), climate-related risk (Jiang et al., 2025; Paolone et al., 2024), and idiosyncratic risk (Izcan, Bektas, 2022), are also frequently addressed.

Based on an analysis of the articles collected, five main trends were identified. First, interestingly, a lack of clear direction regarding the impact of ESG on bank profitability was observed, which constitutes the first main trend in literature. The analysis of factors influencing bank profitability is crucial for understanding how banks can achieve ESG objectives, given the strong link between them (Blaga et al., 2024). Some studies point to a negative relationship in the short term, suggesting that the implementation of ESG practices generates costs that reduce profitability ratios such as ROA (Giannopoulos et al., 2024; Jílková et al., 2025; Kaya, Ertuğrul, 2025). At the same time, empirical results show that this relationship is strongly dependent on the control variables used, such as leverage or capital adequacy, which significantly affect both the level of ESG and bank profitability (Aras, Hacioglu Kazak, 2022; Blaga et al., 2024; Manta et al., 2025).

The second research direction emphasizes the long-term benefits of ESG, particularly in terms of financial stability and risk mitigation. Research indicates that higher ESG scores are associated with lower levels of non-performing loans (NPLs), lower volatility, and greater resilience of banks to shocks (Chiaramonte et al., 2022; Izcan, Bektas, 2022; Tóth et al., 2021). In this context, measures such as the bank Z-score and loan portfolio quality indicators are

particularly significant, as they demonstrate that ESG acts as a stabilizing mechanism, even if it does not directly translate into short-term profitability (Del Sarto, 2025; Porenta et al., 2026).

The third direction of research focuses on the varying impacts of individual ESG factors and the methods used to measure them. Research findings indicate that environmental factors can have a positive impact on financial performance, while social factors are typically neutral or negative, and corporate governance plays a role in promoting stability (Conca et al., 2025; Menicucci, Paolucci, 2023). At the same time, the widespread use of various ESG measures, such as aggregated ESG scores, disclosure indices, or detailed sub-indices (E, S, G), leads to significant heterogeneity in results and hinders their direct comparison (Aras, Hacioglu Kazak, 2022; Fiordelisi et al., 2023; Porenta et al., 2026).

The fourth direction of research emphasizes the importance of corporate governance and institutional factors as moderators of the ESG vs. profitability relationship. Board structure, board/cultural and gender diversity, and independence influence both ESG performance and banks' financial results (Aureli et al., 2026; Menicucci, Paolucci, 2022; Paolone et al., 2024). Additionally, strong governance mechanisms can mitigate the negative effects of ESG controversies and stabilize banks' risk profiles (Del Sarto, 2025).

The fifth trend refers to the role of reputation, disclosures, and market valuation of banks. ESG is increasingly analyzed in the context of market indicators, such as Tobin's Q or the price-to-book ratio, which reflect investor perceptions and the value of the bank (Aras, Hacioglu Kazak, 2022; Manta et al., 2025; Markoulis et al., 2025). At the same time, banks can use ESG disclosures as a tool to mitigate reputational risk and build stakeholder trust (Mandas et al., 2024; Manta et al., 2025).

In addition, a review of the literature indicates that the vast majority of empirical studies rely on econometric modeling, in which the relationship between ESG and bank performance is tested using various configurations of dependent and independent variables. The most commonly used dependent variables are classic profitability measures, such as ROA/ROE, which serve as a benchmark for assessing the impact of ESG (Blaga et al., 2024; Giannopoulos et al., 2024; Kaya, Ertuğrul, 2025; La Torre et al., 2021). At the same time, however, in studies (Chiaramonte et al., 2022; Giordino et al., 2026; Manta et al., 2025; Porenta et al., 2026) ROE/ROA were modeled as independent variables. It is also worth noting that these studies often include a wide range of control variables, such as capital ratios (Tier 1, total capital ratio), financial leverage, and loan portfolio quality, which indicates an attempt to isolate the pure ESG effect on banks' financial performance. The diversity in the selection of dependent and independent variables, as well as the wide range of measures used (e.g., Tobin's Q, NPL, Z-score), confirm the high methodological heterogeneity of the literature, which significantly contributes to the ambiguity of the results obtained.

4. Summary

A review of the literature indicates that the relationship between ESG factors and bank profitability in the European banking sector remains inconclusive. Some studies point to a short-term negative impact of ESG on profitability, which may result from an increase in operating and investment costs. On the other hand, however, some studies point to long-term benefits, including increased financial stability, reduced risk exposure, and greater resilience of banks. The results also show that environmental, social, and corporate governance dimensions affect financial performance in different ways. Furthermore, the results confirm that corporate governance and institutional factors play a key role in shaping the relationship between ESG and profitability.

The review also reveals significant methodological heterogeneity, as most studies rely on econometric models using a variety of dependent and independent variables, such as ROA, ROE, ESG scores, and risk indicators. The study has several limitations, including its focus on European banks and the lack of standardization in ESG measurement. Furthermore, the restriction to selected databases and time frames may have resulted in the omission of relevant studies.

Future research could also look beyond Europe and focus on the long-term effects of applying ESG criteria under different regulatory and market conditions.

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QUALITY FEATURES OF PARTS AND COMPONENTS OF AGRICULTURAL TRANSPORT VEHICLES FROM THE PERSPECTIVE OF UNDERTAKING RESEARCH AND DEVELOPMENT PROJECTS

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Purpose: This publication aims to assess the significance of quality features of components and spare parts of agricultural vehicles from the perspective of manufacturers engaged in research and development (R&D) activities.
Design/methodology/approach: The study used the method of reconstruction and interpretation of the subject literature, which made it possible to define the areas relevant to the development of the research model. This provided the basis for preparing an evaluation sheet, developed through a combination of literature exploration and a study conducted among deliberately selected domain experts. A fuller understanding of the role of quality determinants in enterprises' R&D activities was obtained by verifying the model among deliberately selected enterprises from the agricultural machinery sector.
Findings: From the perspective of enterprises undertaking R&D activities, particular importance is assigned to those quality determinants of parts and components of agricultural vehicles that directly affect the organization's ability to generate innovation and build a lasting competitive advantage. The analysis indicates that technical and innovative factors play a particularly important role. Although enterprises' R&D activities focus primarily on determinants related to innovativeness, functionality, and broadly understood technical quality, environmental, regulatory, and economic conditions should also be taken into account. These factors significantly influence the directions of R&D work and the efficiency of its implementation.
Research limitations/implications: One limitation of the study is the potential subjectivity in the selection and interpretation of determinants, which may differ depending on the specificity of the industry, product type, or operating conditions. In particular, the agricultural machinery sector may have specific priorities. Another limitation is the lack of consideration of changes over time, as the significance of individual determinants may evolve with technological development, regulatory changes, or increasing environmental pressure. Additionally, the analysis does not fully account for organizational and competence-related factors, such as human resources and innovation culture, which have a significant impact on the effectiveness of R&D activities but were not directly included in the set of determinants. Further research

should therefore focus on quantitative operationalization, empirical verification, and extending the scope of analysis to include contextual and dynamic factors, enabling a more complete understanding of the role of quality determinants in enterprises' R&D activities across different sectors.
Practical implications: The theoretical implication of the study is the definition of quality attributes of components and spare parts of agricultural vehicles in the form of a theoretical and design-oriented research model, in which the weight of each attribute depends on the significance assigned to a given determinant. The practical implication is the formulation of recommendations for the design and production of spare parts, as well as for communication with customers regarding the fulfillment of specific quality requirements.
Social implications: The social implications of research on the quality determinants of parts and components, especially in the context of R&D activities, are multidimensional and extend beyond the technical or industrial sector. They include improvements in safety and quality of life, environmental protection, the development of skills and the labor market, as well as an overall increase in the innovativeness and competitiveness of the economy.
Originality/value: The originality of the study lies in the development of a multi-criteria approach to assessing the quality determinants of parts and components of agricultural vehicles from the perspective of R&D activities. The results may serve as a basis for building synthetic indicators that aggregate different determinants into a single quality assessment measure. Such models can be used in industrial practice as tools supporting investment and design decisions.
Keywords: parts and components of agricultural vehicles, research and development activities, product quality, operation.
Category of the paper: research paper.

1. Introduction

Modern enterprises operating under conditions of increasing market competition and dynamic technological change are increasingly focusing their activities on the development of innovative product and process solutions (Damanpour, 1991; Damanpour, Schneider, 2006; Ivanov, Dolgui, 2020). A key element in building competitive advantage is research and development (R&D) activity, which enables not only the improvement of existing products but also the creation of new solutions that respond to changing market needs as well as regulatory and environmental requirements (Singh et al., 2020; Li, Liu, Ren, 2024).

Parts and components of machines are of particular importance in this context, as they constitute fundamental structural elements affecting the quality, reliability, and efficiency of entire technical systems (Nowak, Kijek, Domańska, 2015). In the agricultural machinery sector, where operating conditions are characterized by high variability and heavy loads, the quality of components becomes especially important (Li, Zhang, Chen, 2024). Their properties determine not only the technical efficiency of machines, but also the continuity of agricultural production processes, which directly affects food security and farm efficiency (Kim, Kumar, Kumar, 2012).

The literature emphasizes the multidimensional nature of the quality of parts and components, covering both technical features, such as reliability, durability, performance, and service life, as well as economic, logistical (Achetoui, Mabrouki, Mousrij, 2019), environmental, and formal factors (Zhang, Zhang, 2023). At the same time, the importance of individual determinants may vary depending on the application context and industry specificity. In practice, this means the need to identify and hierarchize those factors that most significantly influence enterprise decisions concerning product design, production, and improvement.

In this context, it becomes particularly important to determine which quality determinants of parts and components of agricultural vehicles are critical from the perspective of manufacturers undertaking R&D activities. Such activities, aimed at creating innovations and improving products, require consideration not only of technical aspects, but also of economic, environmental, and regulatory conditions. The identification of these factors enables better targeting of R&D processes and may increase the efficiency of their implementation (Wolfert, et al., 2017).

Despite the broad interest in quality and innovativeness in the literature (Füller et al., 2021), there remains a research gap concerning the comprehensive assessment of the significance of individual quality determinants in the context of R&D activities, particularly in the agricultural machinery sector. Therefore, it is justified to undertake research aimed at developing an evaluation model that enables the hierarchization of quality factors and their relation to innovation processes carried out by enterprises.

The aim of this paper is therefore to identify and assess the level of significance of selected quality determinants of parts and components of agricultural vehicles from the perspective of enterprises' R&D activities. Achieving this aim will allow for a better understanding of the role of individual factors in innovation processes and may provide a basis for developing tools supporting decision-making in the area of product design and improvement.

The structure of the paper is subordinated to the adopted research objective. The first part presents the theoretical foundations concerning the quality of parts and components and R&D activities. Next, the research methodology is described, including the method of constructing the research model and the procedure for assessing the determinants. The following part presents the analysis of the empirical research results, while the paper concludes with a discussion of the results, final conclusions, and recommendations for business practice and further research.

This approach fits current research trends related to the integration of quality engineering, innovation management, and sustainable development, constituting a contribution to the development of knowledge in the field of managing R&D processes in industrial enterprises.

2. Literature review

Quality constitutes one of the fundamental paradigms of contemporary management and production engineering, determining both the efficiency of manufacturing processes and the competitiveness of enterprises in the market (Tortorella, Fettermann, 2018; Sony, Antony, Douglas, 2020). In a systemic approach, quality is not solely a product feature, but the result of the integrated impact of design, technological, organizational and logistical processes that collectively shape the organization's ability to meet customer requirements as well as technical and regulatory standards (Psomas, Antony, 2017).

In quality management, the process approach plays a special role, as it assumes that quality is created at every stage of the product life cycle - from design, through production, to operation and service (Peng, Jiang, Wang, 2024). In this context, both quality assurance and quality improvement methods are important, as they enable the systematic reduction of process variability and nonconformity costs (Zheng, Zhou, 2025).

In the field of production engineering, quality is closely related to the technical parameters of products and to the stability and repeatability of manufacturing processes (Chaciński, Jaskólski, Pałubicki, 2022). Key aspects include reliability, durability, functionality and dimensional-material consistency (Ng, Jin, Nee, 2011), which directly affect the efficiency of production systems and their ability to meet operational requirements (Wang et al., 2016; Wang et al., 2024).

The contemporary approach to quality also takes into account its multidimensional character, covering not only technical aspects but also economic, environmental and organizational factors (Brundage et al., 2018). In conditions of global competition and growing regulatory requirements, quality becomes a key factor determining the innovativeness of enterprises and their ability to adapt to a changing market environment (Gligor, Esmark, Holcomb, 2015).

As a result, quality in management and production engineering should be viewed as a complex system of dependencies integrating design, manufacturing and product use, while its effective management is a condition for achieving a sustainable competitive advantage (Kaynak, 2003).

In relation to parts and components of vehicles, quality is a multidimensional category encompassing a set of characteristics that determine the product's ability to fulfill specific functions under operating conditions. In the classical sense, quality is understood as the degree to which user requirements, technical standards and expectations regarding product reliability and durability are met (Cooper, 2004).

In the case of machine parts and components, particular importance is attached to properties such as reliability, durability, functionality, efficiency and service life. Reliability refers to the probability that an element will function correctly under specified conditions and over

a specified period, whereas durability and service life describe the component's ability to maintain the required technical parameters over a long period of use. Efficiency, in turn, determines the degree of effectiveness of the entire system in which the given element operates (Davenport, Harris, 2007).

Another important aspect of the quality of parts and components is their compatibility with cooperating elements, including dimensional, material and functional compatibility. Misalignment in this regard may lead to reduced efficiency of the entire technical system or to its premature wear (Wang, Zhang, Duan, 2012).

The literature also emphasizes the importance of factors supporting quality, such as maintainability, ease of servicing and availability of spare parts. These elements directly affect operating costs and the continuity of machine operation, which is particularly important in sectors with high usage intensity, such as agriculture.

Today, non-technical criteria also play an increasingly important role, encompassing economic, ecological, logistical and formal aspects. These include, for example, the price-to-quality ratio, impact on the natural environment, compliance with standards and certification, as well as the quality of information provided by the manufacturer. As a result, the quality of parts and components should be treated as a systemic category, encompassing both the product's physical attributes and its market and operational environment (Jardine, Lin, Banjevic, 2006).

Research and development (R&D) activities are one of the key elements of the modern knowledge-based economy (Ahn, Minshall, 2022). They encompass systematic creative work undertaken to increase the stock of knowledge and to use it to develop new practical applications, including new products, processes and services or their significant improvements.

From an enterprise perspective, R&D plays a strategic role, as it enables the building of competitive advantage based on innovation (Ferreira, Fernandes, Ferreira, 2020). These processes include both basic and applied research, as well as development work aimed at implementing research results into economic practice.

In the context of management and production engineering, R&D activities are closely linked to the processes of design, testing and improvement of technical products. It is particularly important to identify and optimize the quality parameters of products that determine their functionality, reliability and operational efficiency.

An important aspect of R&D activities is their interdisciplinary nature, combining knowledge from engineering, economics, management and environmental sciences. The contemporary approach to innovation also involves taking into account regulatory, ecological and social factors, which influence the direction of technological development of enterprises.

In practice, R&D also includes cost analysis, technological risk assessment and product life-cycle studies. Digital technologies, such as monitoring systems, data analysis and Internet of Things-based solutions, are also becoming increasingly important, as they support decision-making processes and increase the efficiency of development work.

The relationship between the quality of parts and components and R&D activities is bidirectional. On the one hand, R&D results determine the quality level of products by introducing innovative design, material and technological solutions. On the other hand, the analysis of quality and its determinants serves as a starting point for initiating new R&D projects.

In practice, this means that identifying critical quality features of components can serve as a basis for defining the directions of technological development of enterprises. Particularly important are those features that affect the reliability, durability and economic efficiency of products, as they determine both user satisfaction and market competitiveness.

Consequently, the quality of parts and components and R&D activities should be considered mutually interconnected domains that together shape enterprises' ability to create innovations and maintain a competitive position in the market.

3. Material and method

3.1. Research aim and hypotheses

The research hypotheses presented below were formulated in direct relation to the aim of the study, namely to determine the significance of quality features of parts and components of agricultural vehicles from the perspective of manufacturers making decisions in the area of research and development (R&D):

H1: *In the decision-making process regarding the directions of R&D works of manufacturers of parts and components of agricultural vehicles, technical features (reliability, durability, safety, efficiency) are assessed as more significant than features of a logistical, formal or after-sales nature.*

H2: *The level of significance assigned to innovativeness and modernity features determines the prioritization directions of R&D activities in companies producing parts and components of agricultural vehicles.*

H3: *Features related to long-term operational efficiency (durability, service life) are an important criterion for resource allocation in manufacturers' R&D activities.*

H4: *Environmental aspects have relatively low importance in the R&D activities of manufacturers of parts and components of agricultural vehicles.*

H5: *Logistical and after-sales factors play a supporting role in the quality assessment from the R&D perspective and do not constitute the main determinant of decisions regarding the development directions of parts and components of agricultural vehicles*.

3.2. Research implementation scheme

In order to ascertain opinions regarding the level of significance of quality features of components and spare parts from the perspective of manufacturers undertaking R&D work, and also to verify the needs and challenges in improving them, a cycle of studies was conducted. These included selected experts (purposely chosen representatives of micro, small, medium, and large enterprises in the agricultural machinery sector; specialization: production of parts and components of means of agricultural transport).

The research was conducted from November 2025 to April 2026. In the first stage of the research, as a preparatory study[A^0] the author used the methods of literature review[A^{01}] and an expert survey[A^{02}]. The preparatory study conditioned the conduct of the main study [B^{03}]. The research scheme is illustrated in Figure 1.

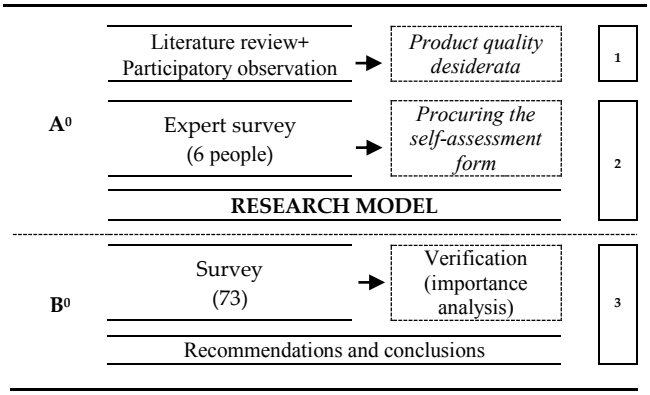

Figure 1. Research implementation scheme.

Source: Author's own elaboration

In summary, the research included a preparatory phase and the main study. The preparatory phase involved literature research, participant observation, and an expert survey involving six experts, which resulted in the identification of product quality requirements and the development of a self-assessment sheet that served as the basis for the research model. A survey was then conducted among 73 respondents to verify the significance of the analyzed features and to formulate recommendations and conclusions.

3.3. Formulating the research model [A^0]

Using the method of reconstructing and interpreting available studies and subject literature supported by the author's observations, a catalog of desiderata was selected, relating to the significance of quality features of components and spare parts of agricultural vehicles from the perspective of manufacturers undertaking R&D activities. In the next stage, a team of six experts was appointed to work on ideas and solutions in this area.

The knowledge and experience of experts in the area defined by the conducted research was verified on the basis of a competence coefficient determined according to the following formula:

$$K = \frac{1}{2}(K_i+K_a) \quad \text{gdzie } 0<K\leq 1 \qquad (1)$$

The in formativeness coefficient (Ki) was determined based on self-assessment (from 0 to 10 points) multiplied by 0.1. The argumentation coefficient (Ka) was determined on the basis of an interview with the expert. Competence, expressing the expert's qualification level, was determined based on practical activities and knowledge of the sector.

The study was based on the author's creative problem-solving method – written brainstorming (brain writing). This brainstorming approach allowed for preparing a list of variables referring to the quality features of components and spare parts from the perspective of manufacturers undertaking R&D work (Table 1).

Table 1.
Quality features of parts and components of agricultural vehicles – perspective of R&D works

Lp.	Determinant	Description	Category
1.	Reliability	is the measure of the ability of a component or part to perform its functions according to the assumptions for a specified period and under specified conditions. It is a feature that defines how effectively an agricultural machine or vehicle can avoid failures or disruptions in its operation, which, in turn, ensures continuity of operation (field work). It can be measured by various indicators, such as time between failures, probability of damage. It is the certainty or predictability that a given component or part will operate as expected under operating conditions.	Technical
2.	Functionality	The range of actions and possibilities that the component or part offers to the user. It defines what tasks can be performed using the given part or component. It is usually described in the form of functional requirements, which specify specific functions, operations and interactions possible within the given system (e.g., the drive system). It is also assessed in terms of effectiveness in accomplishing intended tasks.	Technical
3.	Durability	is the average time elapsed from the start of operation of a part or component to the occurrence of the first failure (MTTF – Mean Time To Failure). In the case of complex products, the key may be the mean time between failures (MTBF – Mean Time Between Failures) that elapses between subsequent failures of the same part or component. The longer the mean time between failures of a given element, the more durable the product.	Technical
4.	Performance	Parts and components allow maintaining the previous performance level of the machine.	Technical
5.	Service life	Specifies the time, use or number of working cycles during which a given part or component maintains sufficient technical parameters to fulfill its function in a reliable and efficient manner. Measuring the product's service life is essential for assessing its durability and planning maintenance and replacement schedules to ensure the continuity of the machine's operation.	Technical

Cont. table 1.

6.	Maintainability	The possibility of preventing failures and extending the life of elements; easy lubrication of moving parts, such as bearings, prevents wear and premature failures.	Operational
7.	Modernity, innovativeness	- Can improve the machine's performance, reduce fuel consumption and increase operator comfort. - Often use the latest technologies, such as telematics systems, automation or IoT (Internet of Things), which can facilitate the monitoring and management of the machine and improve its performance. - Parts or components meet the latest industry norms and standards, which translates into safe and effective use. - Designed in such a way that they can be easily expanded or updated in the future, allowing the machine to adapt to changing needs and working conditions.	Innovations
8.	Safety	Designed and manufactured according to the highest safety standards.	Technical
9.	Compatibility with cooperating elements	Exactly matched to the original element, taking into account dimensions, technical specifications and materials used in production.	Technical
10.	After-sales information, offer, logistics	Manufacturer's information, such as catalog numbers and assembly and operating instructions, can help ensure that a given part or component actually matches the design.	Logistics
11.	Environmental friendliness	- Choice of ecological materials, environmentally friendly, such as biodegradable, renewable materials. - Recycling (restoring used parts to circulation). - Reduction of emissions associated with the operation of agricultural machines, e.g., by improving fuel efficiency. - Durability (the need for less frequent replacement and generating less waste). - Eco-certificates.	Ecological
12.	Compliance with regulations and standards	Quality tested and possessing the necessary certificates confirming compliance with standards.	Formal
13.	Workmanship and aesthetics	Manufactured from high-quality materials and according to specifications, with an aesthetic finish of components and spare parts, such as anti-corrosion coatings and finishes, which can help prevent corrosion and extend the durability of elements. Carefully designed and manufactured elements may indicate attention to quality and detail.	Formal
14.	Warranty conditions	Attractive warranty conditions (duration and scope of warranty, terms of fulfillment) that give the customer certainty regarding the quality and reliability of the products.	Formal
15.	Price	Product analysis in terms of value relative to price and other factors such as durability, reliability and long term costs; the balance between price and quality (parts or components ensuring the optimal functioning of agricultural machines). A higher purchase price of parts can be offset by lower costs related to the need for replacement and repairs in the future.	Economic
16.	Availability	- It is an important factor that can be considered as an indication of quality. - Failure to maintain stocks of spare parts and components may indicate low quality.	Logistics
17.	Delivery speed	Parts and components delivered quickly in case of failure increase the reliability of the machine and minimize losses associated with downtime. A quick response and product availability can demonstrate the company's commitment to full customer service.	Logistics

Cont. table 1.

18.	Supplier reputation	Complying with the accepted quality standards in the execution of components and spare parts can positively influence the manufacturer's image.	Formal
19.	Packaging (aesthetics, information, handling)	The packaging of spare parts and components indicates the quality of the product, effectively protects the contents, facilitates identification and provides additional valueto the customer.	Logistics

Source: Author's own elaboration.

The assessment of the quality of components and spare parts of agricultural machines, understood as means of agricultural transport, is a multi-criteria issue covering technical, operational, economic, and environmental aspects. Key importance is attributed to operational properties such as reliability, durability, and service life, which determine the ability of elements to operate for a long time and without failure under specified operating conditions. Functionality and compatibility of parts with cooperating elements are also important complements, as they ensure the proper functioning of the entire technical system.

The evaluation process also takes into account operational aspects, such as ease of maintenance, availability of parts, and delivery speed, which affect the continuity of machine operation and the reduction of downtime. The quality of workmanship, user safety, and the degree of innovation resulting from the application of modern technologies also play a significant role.

Formal and environmental factors, including compliance with applicable standards and certifications, as well as environmental friendliness, are also important. The evaluation is complemented by elements related to after-sales service, such as warranty terms, access to technical information, and supplier reputation. The analysis is further supplemented by economic criteria, particularly the price-to-quality ratio, as well as logistical and operational aspects, including product packaging.

Such a comprehensive approach enables an objective and multifaceted assessment of the quality of components and spare parts, which is crucial for ensuring the effective and reliable operation of agricultural machines.

4. Empirical exemplification

4.1. Characteristics of respondents

The scope of the problem required involving sector specialists in the expert study. Therefore, representatives of enterprises from the agricultural machinery sector, specifically those producing parts and components of agricultural vehicles, were selected for the next stage of the research. These individuals were actively involved in logistics and production processes in their companies. They were also initiators of change, seeking opportunities to implement

new products, undertake innovative activities, apply their own ideas to improve their own work and that of others, and, above all, understand the impact of R&D activities on the quality and performance of the company. Experts were selected based on characteristics such as competence, creativity, the ability to solve complex problems, a positive attitude toward research, constructive thinking, and self-criticism.

The main stage of the expert research was conducted from November 2025 to January 2026. For the purpose of collecting research material, a specially designed assessment questionnaire was prepared, and the data collection process was carried out using direct interview techniques as well as an online format. In total, the study included 73 experts.

The population of the surveyed experts consisted of representatives of manufacturing companies operating in the agricultural machinery sector (specialization: production of parts and components). The respondents were experts representing: micro – 6 persons (8.22%), small – 22 persons (30.14%), medium – 39 persons (53.42%), and large – 6 persons (8.22%) enterprises.

Considering the distribution by predominant type of production, mass or large-batch production was declared by 38.36%, short batch production by 53.42%, and unit production by 8.22%. In 35.62% of the companies, production mainly involved the assembly of components into finished products (purchased from external suppliers), whereas 64.38% of companies indicated a multi-stage production process, in which components and then finished products (parts and components of agricultural vehicles) are created in sequence. For the first group of companies, the majority fall into the category of suppliers of components dedicated to first assembly.

Regarding age distribution, 6.85% of respondents were under 30 years old, 26.03% were in the 31-40 age range, 30.14% in 41-50, 21.92% in 51-60, and 15.07% of respondents were over 60 years old.

Among the respondents, the majority had secondary or higher education, of which 67.12% of owners had higher education, 19.18% – secondary, and 13.70% – basic (vocational) education.

In the course of the research, an attempt was made to interpret the results based on the experts' declarations. For this purpose, a five-point scale was used, where 1 indicated a very low correlation of the parameter with expectations, and 5 – very high. The next step was to obtain the data and interpret it.

The structure of the surveyed sample indicates the predominance of medium-sized and small enterprises, which suggests that the obtained results reflect the perspective of entities characterized by relatively high flexibility and adaptability, an important aspect from the perspective of R&D activities. At the same time, the small share of large enterprises may limit the possibility of fully relating the results to entities with a high level of formalization and greater resource availability.

The predominance of short-batch production and the significant share of mass production indicate the diversified nature of the surveyed enterprises' activities, combining the need for design flexibility with the requirements of process standardization. At the same time, the dominance of multi-stage production processes indicates a high degree of technological integration, which is conducive to conducting R&D activities and implementing innovations.

The profile of respondents, consisting mainly of people aged 31-50 and individuals with higher education, indicates a high level of competence and experience in the surveyed group, which increases the credibility of the obtained assessments. At the same time, the participation of practitioners with diverse levels of education makes it possible to consider both strategic and operational perspectives.

Considering the purposive sampling and the limited size of the sample, the results should be interpreted as characteristic of the analyzed group of enterprises from the agricultural machinery sector. At the same time, they constitute a valuable basis for identifying directions of R&D activities and assessing the significance of quality determinants in industrial practice.

4.2. Research results

The aim of the conducted analysis was an in-depth determination of the level of significance of quality features of parts and subassemblies of agricultural machinery in the context of manufacturers undertaking research and development (R&D) activities. The obtained results (Table 2) enable not only the identification of the most important determinants of quality, but also indicate directions for resource allocation in the processes of product design and improvement.

The analysis of the distribution of ratings indicates a clear dominance of determinants of a technical and innovative nature. Modernity and innovativeness received the highest rating (4.64), which clearly confirms the growing importance of advanced technologies in the machinery and spare parts sector. In practice, this means that manufacturers should concentrate R&D activities on implementing solutions such as automation, telematics systems, and integration with digital technologies. Innovativeness is no longer a distinguishing factor but becomes a standard determining market competitiveness.

The next group, with a very high level of significance, consists of features directly related to the operational efficiency of the product, such as efficiency (4.58), safety (4.58), and reliability (4.52). These results indicate that users expect, above all, trouble free, continuous operation of machines, minimization of downtime, and maximization of operational efficiency. From an R&D perspective, this means the need to intensify efforts on improving structural quality, optimizing mechanical systems, and using materials with increased wear resistance. A particularly important element here is a system level approach that takes into account the interaction of individual components throughout the entire operational life cycle.

Table 2.
Results of own research

Group	Descriptors	1	2	3	4	5	Mean
		% ANSWERS					
Quality features of agricultural machinery components – R&D perspective	Reliability	-	2	2	25	44	4,52
		-	2,7	2,7	34,2	60,3	
	Functionality	-	-	7	25	41	4,47
		-	-	9,6	34,2	56,2	
	Durability	-	2	5	22	44	4,48
		-	2,7	6,8	30,1	60,3	
	Efficiency	-	1	7	17	48	4,53
		-	1,4	9,6	23,3	65,8	
	Lifespan	-	3	8	23	39	4,34
		-	4,1	11,0	31,5	53,4	
	Maintenance	2	4	18	27	22	3,86
		2,7	5,5	24,7	37,0	30,1	
	Modernity and innovativeness	-	-	2	22	49	4,64
		-	-	2,7	30,1	67,1	
	Safety	-	-	4	23	46	4,58
		-	-	5,5	31,5	63,0	
	Degree of compatibility with cooperating elements	2	3	19	29	20	3,85
		2,7	4,1	26,0	39,7	27,4	
	Information, offering, after-sales logistics	1	2	16	33	21	3,97
		1,4	2,7	21,9	45,2	28,8	
	Environmental friendliness	1	3	10	35	24	4,07
		1,4	4,1	13,7	47,9	32,9	
	Compliance with regulations and standards	-	-	7	22	44	4,51
		-	-	9,6	30,1	60,3	
	Care and aesthetics of workmanship	-	4	9	29	31	4,19
		-	5,5	12,3	39,7	42,5	
	Warranty terms	3	8	26	22	14	3,49
		4,1	11,0	35,6	30,1	19,2	
	Price	1	-	4	17	51	4,60
		1,4	-	5,5	23,3	69,9	
	Delivery speed	1	3	17	25	27	4,01
		1,4	4,1	23,3	34,2	37,0	
	Availability	3	7	21	25	17	3,63
		4,1	9,6	28,8	34,2	23,3	
	Supplier reputation	3	7	22	25	16	3,60
		4,1	9,6	30,1	34,2	21,9	
	Packaging (aesthetics, information, handling operations)	2	5	21	29	16	3,71
		2,7	6,8	28,8	39,7	21,9	

Source: own study.

An important conclusion is also the very high importance of price (4.60), interpreted not as the unit cost but as the quality to price ratio. This means that R&D activities should be aimed not only at maximizing technical parameters but also at optimizing costs throughout the entire product life cycle. In practice, this implies employing concepts such as life cycle cost analysis (LCC) or design-to-cost. Manufacturers should strive to achieve a compromise between high quality and an acceptable cost level, which is of crucial importance for customers' purchasing decisions.

High ratings of determinants such as durability (4.48), functionality (4.47), and lifespan (4.34) indicate the significance of long-term operational efficiency. Users prefer solutions characterized by a long operational life and a low frequency of failures. In the context of R&D, this means the need to develop material technologies, improve processing methods, and implement simulation methods that enable the prediction of wear and failures. It is also crucial to employ design oriented towards reliability (Reliability Engineering).

Determinants of medium level of significance, such as environmental friendliness (4.07), availability (4.01), and care and aesthetics of workmanship (4.19), indicate the growing role of sustainable development aspects and quality of workmanship. Although they are not the most important selection criteria, their significance is systematically increasing, due both to legal regulations and changing market expectations. Accordingly, manufacturers should include in their R&D activities the development of technologies that limit environmental impact, such as eco-friendly materials, recycling processes, or solutions that improve energy efficiency.

In contrast, the lowest ratings were obtained by determinants related to logistics, after-sales service, and formal aspects, such as warranty conditions (3.49), supplier reputation (3.60), delivery speed (3.63), and packaging (3.71). These results suggest that these factors are not a key focus in the context of R&D activities. They can be treated as supporting elements that influence the overall perception of quality, but they do not determine it to the same extent as technical and functional parameters. At the same time, it should be emphasized that marginalizing them in operational activities may negatively affect the customer experience; therefore, they should be developed in parallel, although not necessarily as part of main R&D investments.

A synthetic analysis of the results allows distinguishing three levels of quality determinants. The first level includes core quality features, i.e. reliability, efficiency, safety, and durability, which directly determine the product's functionality. The second level consists of supporting features such as functionality, lifespan, and the quality-to-price ratio, which affect the long-term operational efficiency. The third level includes supplementary features related to environmental, aesthetic, and logistical aspects. This structure indicates that users make purchasing decisions primarily on the basis of the product's functional and operational value, whereas the remaining factors serve a differentiating role.

The analytical conclusions clearly indicate that manufacturers' R&D activities should be primarily directed towards the development of technical and innovative features that directly influence operational efficiency, reliability, and safety. Also of key importance is integrating the technological approach with the economic one, which implies the need to design cost-optimal solutions throughout the product life cycle. In addition, environmental aspects and workmanship quality should be developed, as they may constitute a significant element of building competitive advantage in the longer perspective.

In summary, the study results constitute an important basis for formulating R&D strategies in manufacturing enterprises. They enable rational allocation of resources and a focus on those areas that generate the greatest value for the end user. Under conditions of increasing market competition and dynamic technological changes, such an approach constitutes a key factor for success and the long-term competitiveness of manufacturers.

5. Discussion recommendations and conclusions

The presented results allow us to identify a hierarchy of importance for quality characteristics of parts and components of agricultural transport vehicles from the perspective of manufacturers undertaking research and development activities. The obtained results indicate a clear dominance of technical and innovative characteristics, which is consistent with trends described in the literature on quality engineering, product management, and innovation theory. The particularly high ratings for modernity, innovation, reliability, safety, and efficiency confirm that the contemporary perception of quality goes beyond classic functional requirements and encompasses the product's ability to adapt technologically and integrate with solutions characteristic of Industry 4.0. Therefore, it can be assumed that these characteristics constitute potential areas for prioritizing research and development activities by companies.

The significant importance assigned to durability, longevity, and value for money indicates that the development process of new products should take into account long-term operational efficiency and economics of use. These results align with the concepts of total cost of ownership (TCO) and product lifecycle management (LCC), emphasizing the need to design solutions that reduce the risk of failure, extend service life, and reduce operating costs. This means that manufacturers' research and development activities should focus not only on improving technical parameters, but also on increasing the durability and reliability of components and improving their economic efficiency.

The results also indicate that logistical, formal, and after-sales factors primarily serve a supporting role and are not primary determinants of development decisions. A similar trend was observed with respect to environmental aspects, which were rated relatively lower in importance. However, this does not mean that these areas are marginalized, but rather that they are complementary to technical and operational characteristics. It can also be assumed that with the ongoing transformation towards a sustainable economy and the tightening of regulatory requirements, the importance of environmental aspects will systematically increase, also influencing the directions of future research and development.

The study results also allow for the formulation of practical implications for companies producing parts and components for agricultural transport vehicles. It seems justified to focus R&D activities primarily on the development of solutions that increase the reliability, safety,

durability, and efficiency of components. This implies a need for broader use of reliability engineering methods, FMEA analyses, wear modeling, fatigue testing, and durability testing during the design phase of new products. At the same time, the high importance assigned to modernity and innovation indicates the need to intensify efforts related to product digitization, the development of intelligent components, technical condition monitoring systems, telemetry, and solutions that align with the concept of Industry 4.0.

The high ranking of features related to long-term operational efficiency also indicates the need to implement a product lifecycle approach. From the perspective of companies, this means designing products with consideration of total operating costs, the potential for reducing failure rates, and extending the useful life of components. Such an approach can be a crucial element in building competitive advantage and enhancing the value of offered solutions.

The analysis thus allows us to conclude that the hierarchy of quality features is multi-level, with technical, innovative, and operational features being crucial for potential research and development activities, while organizational, logistical, and formal factors play a complementary role. Consequently, it can be assumed that effectively building a competitive advantage for manufacturers of agricultural transport parts and components requires the integration of classic quality engineering methods with modern technological solutions and an approach that takes into account product lifecycle economics.

It should also be emphasized that the conducted study addressed the perceived importance of quality features from the perspective of decision-making in the area of research and development, not the actual mechanisms of enterprise resource allocation. Therefore, the obtained results should be interpreted as a reflection of preferences regarding potential directions for prioritizing R&D activities, rather than as direct evidence of the impact of individual characteristics on actual investment expenditures or the effects of innovation activity. This also serves as a premise for further research that includes analysis of actual decision-making processes, the structure of R&D expenditures, and the results of implemented innovations.

6. Recommendations

In the agricultural machinery sector, the design of parts and subassemblies requires a systemic approach resulting from the specificity of their operation, including high load variability, exposure to environmental factors such as dust, moisture, and corrosion, as well as seasonal use. Consequently, product competitiveness should be analyzed in multi-criteria terms, taking into account technical, economic, and operational properties throughout the entire product life cycle.

The fundamental determinant of competitiveness remains reliability, understood as the ability of a subassembly to perform its intended function without failure within a specified time and under specified operating conditions. In the case of agricultural machinery, reliability is particularly important due to the high costs of downtime during periods of intensive fieldwork. For this reason, design should be based on reliability engineering methods, including FMEA analysis, wear process modeling, and assessment of the fatigue resistance of materials.

Durability and lifespan of components are also important factors, understood as the ability to maintain operational parameters over a long period of use. In this regard, design focused on minimizing the degradation of material and geometric properties is of key importance, especially under cyclic and environmental loads. In the relevant literature, durability is identified as one of the basic parameters determining Total Cost of Ownership, which directly influences users' purchasing decisions.

Another significant dimension is functional efficiency, encompassing the ability of a subassembly to perform its intended functions with optimal use of resources. In practice, this means designing solutions with high operational efficiency and low failure rates, which can be achieved through structural optimization methods and numerical simulations.

The economic efficiency of the product, analyzed from a life-cycle cost perspective, also plays an important role. In the agricultural machinery sector, users' investment decisions are strongly determined by the relationship between purchase cost and operating costs, including service, parts replacement, and losses resulting from downtime. Accordingly, design should aim to minimize total costs while maintaining the required functional parameters.

In the case of spare parts, dimensional and functional compatibility with original components is also of particular importance, as even small deviations may lead to system malfunctions or accelerated wear of cooperating elements. Consequently, a high level of manufacturing precision and quality control constitutes an important element of competitive advantage.

In addition, the growing significance of environmental aspects should be considered, including recyclability, reduced material consumption, and reduction of the negative environmental impact of operation. Although in the agricultural machinery sector these factors do not always constitute a primary determinant in purchasing decisions, their importance is systematically increasing due to tightening regulations and pressure toward sustainable development.

In summary, the competitiveness of parts and subassemblies for agricultural machinery is determined by an integrated set of features, including reliability, durability, functional efficiency, life-cycle economy, and technological integration capability. Therefore, achieving market advantage requires a holistic approach that combines classical quality engineering methods with modern concepts of digitalization and cost optimization.

7. Summary

The aim of this article was to determine the significance of quality features of parts and subassemblies of agricultural machinery from the perspective of manufacturers making decisions related to research and development (R&D) activities. This aim was achieved through the empirical identification and hierarchization of quality determinants, which provide a basis for assessing product development directions in the agricultural machinery sector.

The obtained results clearly indicate the dominance of technical features in assessing the significance of quality determinants. In particular, the highest importance was attributed to innovativeness and modernity, reliability, efficiency, and safety, which confirms that these categories constitute fundamental criteria determining the directions of R&D activities in the analyzed area. At the same time, significant importance was assigned to the quality-to-price ratio, which highlights the economic dimension of quality assessment understood in terms of user value and life-cycle costs.

The study results allowed for a positive verification of the formulated research hypotheses. It was confirmed that technical features have a significantly higher rank than logistical, formal, and after-sales features in the context of R&D decisions (H1). The key role of innovativeness and modernity in prioritizing product development directions was also verified (H2). The significance of features related to long-term operational efficiency, particularly durability and lifespan, was indicated as a criterion for allocating R&D resources (H3). Environmental aspects received a relatively lower level of significance, indicating their supplementary role in current R&D decisions (H4). The study also confirmed the auxiliary role of logistical and after-sales factors in the quality evaluation process from the product development perspective (H5).

In summary, the conducted study enabled the identification of a hierarchical structure of the significance of quality features of parts and subassemblies of agricultural machinery, highlighting the dominant role of technical and innovative determinants in shaping R&D decisions. The obtained results provide empirical confirmation of the need for manufacturers to focus their development activities on improving reliability, durability, and operational efficiency, while simultaneously taking into account the growing importance of economic and environmental conditions in the long term perspective of competitiveness.

The study's main limitations include the purposive sampling of enterprises and the dominant share of medium-sized companies, which accounted for 53.42% of respondents. The sample structure may have influenced the hierarchy of assessed quality determinants, primarily reflecting the perspective of enterprises in this category. Consequently, the obtained results should be interpreted with caution, as their generalizability to the entire population of producers of agricultural transport parts and components is limited.

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SMART CITY MANAGEMENT AND CYBERSECURITY – CHALLENGES AND DIRECTIONS FOR DEVELOPMENT

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Purpose: This article addresses the key issue of smart city development in Polish cities. The aim of the article is to identify the main challenges related to digital security in the context of smart city management and to identify directions for further development in this area. The analysis was conducted under the assumption that the development of smart cities is based on the intensive use of digital technologies, the functioning of which depends on an adequate level of digital security. It was also assumed that cybersecurity is one of the key factors determining the efficiency, reliability, and sustainable development of smart cities, and that ensuring it requires a comprehensive approach encompassing technological, organizational, legal, and social aspects. The growing dependence on digital infrastructure generates new threats to urban security.
Design/methodology/approach: The aim of this work was achieved through theoretical and practical analysis. The article identifies challenges and directions for development in the field of digital security in smart city management. The results presented in the paper demonstrate the threats present in Polish smart cities.
Findings: The research results enabled the identification of key directions of technological development and the level of digital security in cities. Improving the quality of life of their residents depends on modern technological and IT solutions that support urban systems. Theoretical and research analysis identified challenges and directions of development in the field of digital security in smart cities.
Research limitations/implications: The topic of this article is an important and timely research issue. The topic is particularly relevant given the increase in cyberattacks in Poland in recent years. Further research and expansion of its scope are recommended. The author plans to continue her research on this topic.
Practical implications: This article presents options for implementing digital security measures that businesses and consumers consider important. The identified solutions can help determine the direction of business security development.
Social implications: The presented research and development directions allow us to understand the importance of digital security in cities. This topic influences public awareness of security in smart cities. At the same time, city residents will learn about the benefits of implementing technological solutions that will improve their lives and functioning in cities.
Originality/value: The added value of this article is the opportunity to explore digital security solutions within the smart city concept. The topic presented is timely and particularly relevant for city dwellers.

Keywords: smart city, cybersecurity, smart city management.
Category of the paper: Research paper.

1. Introduction

The growing urban, environmental, and socio - economic challenges faced by modern cities are driving the dynamic development of the smart city concept. This concept encompasses a wide range of strategies primarily aimed at improving the quality of life in the city through the integration of information and communication technologies (ICT), while also promoting citizen participation and effective governance (Smalec, 2025). The integration of advanced information and communication technologies, along with data analytics, enables more efficient management of urban infrastructure, improves the quality of life for residents, and optimizes the use of resources (Giuliodori et al., 2022; Alahi et al., 2023; DeJong, Joss, Taeihagh, 2024). At the same time, the growing reliance on digital infrastructure generates new threats in the area of security (Xia et al., 2024; Sha, Taeihagh, De Jong, 2024). There is a need to build the resilience of smart cities by focusing on local capabilities to prevent threats - natural, social, and technological (Gracias et al., 2023; Jonek-Kowalska, 2018). A key role in this process is played by the development of digital infrastructure and the implementation of sustainable development principles, which together form the foundation for more functional and crisis-resilient cities (Ancillai et al., 2023). The increasing risk of threats resulting from civilizational development is one of the fundamental problems of modern cities (Chodyński, 2019). Digital security is becoming a key element of smart city management, determining the stability of urban systems and the protection of data. The complexity of the technological environment and its vulnerability to cyberattacks make it necessary to ensure user privacy. The aim of the article is to identify the main challenges related to digital security in the context of smart city management and to indicate directions for further development in this area. The following hypothesis was formulated in the article: effective smart city management requires the implementation of a comprehensive approach to cybersecurity and risk management. This hypothesis led to the formulation of the following research questions:

- What should be the main focus of future efforts aimed at integrating cybersecurity with smart city management processes?
- What are the most significant challenges related to digital security in the management of smart cities?
- In what direction should further activities and research concerning smart city management and cybersecurity be developed?

Managing smart cities requires a multi-faceted approach to risk management and cybersecurity.

2. Digital security of cities

Cities, as population centers, are interconnected and interdependent socio-economic systems (Desroches, Taylor, 2018; Dominiak, Gawkowski, Wasielewski, 2022). In a smart city, the use of data, information, and information technologies provides residents with an efficient and effective system for delivering public, social, technical, and administrative services (Braun et al., 2018). Smart city management involves using digital technologies and data analytics to effectively manage urban infrastructure, resources, and services in order to improve residents' quality of life (Ripoll González, Gale, 2023). Through the implementation of advanced technologies, the goal is to integrate and develop the distributed systems currently in use in cities (Shams et al., 2020). That is why digitalization is becoming the cornerstone of modern urban management. It enables cities to operate faster, more efficiently, more sustainably, and, above all, in a way that is better tailored to the needs of their residents. Technological solutions in cities cover various areas: from the digitization of public services, through sustainable transportation and energy efficiency, to civic engagement (Curtis, Mont, 2022). Technological changes necessitate the adoption of the highest cybersecurity standards, as this is the only way for a city to develop in a sustainable manner (Hussain et al., 2021). The key technologies supporting smart city management, such as Information and Communication Technologies (ICT) and the Internet of Things (IoT), are presented in Table 1.

Table 1.
Technologies supporting Smart Cities

Type	Application
Information and Communication Technologies (ICT)	They encompass techniques for processing, collecting, and transmitting information. They are essential in crisis management operations because they enable the representation of reality, the creation of knowledge resources, decision-making, and the coordination of initiatives.
Geographic Information System (GIS)	It is used to enter, collect, process, and visualize geographic data for the purpose of recording and visualizing changes in events, as well as analyzing statistical data and data on technical infrastructure. GIS is a key decision-making tool in urban development planning.
Internet of Things (IoT)	It enables every participant in a given process to communicate by exchanging data and information. These systems respond autonomously to events as they occur and initiate processes and actions without direct human intervention. It creates an urban sensing system that informs authorities about the current state of the city.
Internet of Services (IoS)	It uses data aggregation and integrates multiple services to support decision-making and communication. Online services streamline residents' interactions with government agencies.
Large Datasets (Big Data)	They are characterized not only by a large amount of information, but also by the diversity and speed of its processing. This refers to the rapid growth in the scale of data generated by technologies (including IoT), which require advanced analytical techniques.

Source: Own elaboration based on Sienkiewicz-Małyjurek, 2020; Drăgoicea et al., 2018; Bernardini et al., 2017; Martin et al., 2019; Jing Ran, Nedovic-Budic, 2016; Alahi et al., 2023.

In a smart city, technology is central to both infrastructure and decision-making. Rapid development is made possible by millions of sensors that collect data on various aspects of the city's operations, automated administrative procedures, strategic planning, and management based on advanced analytics (Korenik, 2017; Al-Turjman, Zahmatkesh, Shahroze 2022).

Today, there is a need to build a security system for smart cities by focusing on the ability to prevent threats, including natural, social, and technological ones (Gracias et al., 2023; Jonek-Kowalska, 2018). Resilience to threats in urban crisis management has three dimensions (Arafah, Winarso, Suroso, 2018):

- technical (e.g. resilience of critical infrastructure),
- organizational (e.g. resilience of public administration systems),
- social (resilience of citizens).

The lack of appropriate forms of digital security for increasingly advanced technological investments may hinder urban development and discourage people from investing in smart city solutions. Therefore, cybersecurity in a smart city is a key element linking social expectations with rapid development (Houichi, Jaidi, Bouhoula, 2024). Threats occurring in cities can be divided into two types, which are presented in Table 2.

Table 2.
Classification of selected threats in Smart City technology

Internal area	External area
transfer or sale of digital data to unauthorized persons or institutions	hacking attacks
sabotage	break-ins
lack of adequate control over information processing processes	false information
technical errors	hardware integrity breaches

Source: Own elaboration based on Kitchin, Dodge, 2019, p. 47.

Table 2 classifies two types of threats associated with smart city technologies. Among the internal threats, the most significant risk identified by respondents is the sharing or sale of digital data to unauthorized individuals or institutions. Among the external threats, respondents identified cyberattacks carried out by hackers as the most significant concern. Ongoing urbanization is leading to an increase in the number of people living in urban areas, which are potentially more vulnerable to cyberattacks. Consequently, smart city management cannot be considered solely in terms of efficiency and innovation but must include a comprehensive approach to digital security. The implementation of smart city solutions involves the collection and processing of vast amounts of data, often of a sensitive nature (Habib, Alsamadi, Prybutok, 2020; Ryalat, ElMoaqet, AlFaouri, 2023). In cities, the resources and systems most exposed to cyberattacks include, among others: energy networks, intelligent transport systems, monitoring and public safety systems, building management systems, and digital service platforms (Hassine et al., 2025). Traffic management, energy, public transport, and security systems are increasingly dependent on ICT networks, which makes them vulnerable to cyberattacks, system failures, and privacy breaches (Bansal, Mukherjee, Gairola, 2017). The digitalization of urban

space generates new risks, particularly in the area of digital security, which is becoming one of the key aspects of the functioning of smart cities. The spread of cyberattacks is also driven by the emergence of new types of threats resulting from the development of innovative technologies and their increasing accessibility, such as AI models.

3. Cybersecurity analysis in Poland in the years 2020-2025

Digital security in Poland is a very important element of the functioning of the state. Technological and information development requires the implementation of appropriate security procedures concerning the protection of data, IT systems, and user privacy. Therefore, in 2018, the National Cybersecurity System was established in Poland. Within this system, three national - level CSIRT teams operate at the operational level (www.gov.pl):

1) CSIRT GOV – the Computer Security Incident Response Team operated by the Head of the Internal Security Agency.
2) CSIRT MON – the Computer Security Incident Response Team operated by the Minister of National Defence.
3) CSIRT NASK – the Computer Security Incident Response Team operated by the Research and Academic Computer Network – National Research Institute.

In recent years, an increase in the activity of groups engaged in illegal activities in the digital world has been observed. The number of incidents recorded by CSIRTs has also increased (Figure 1).

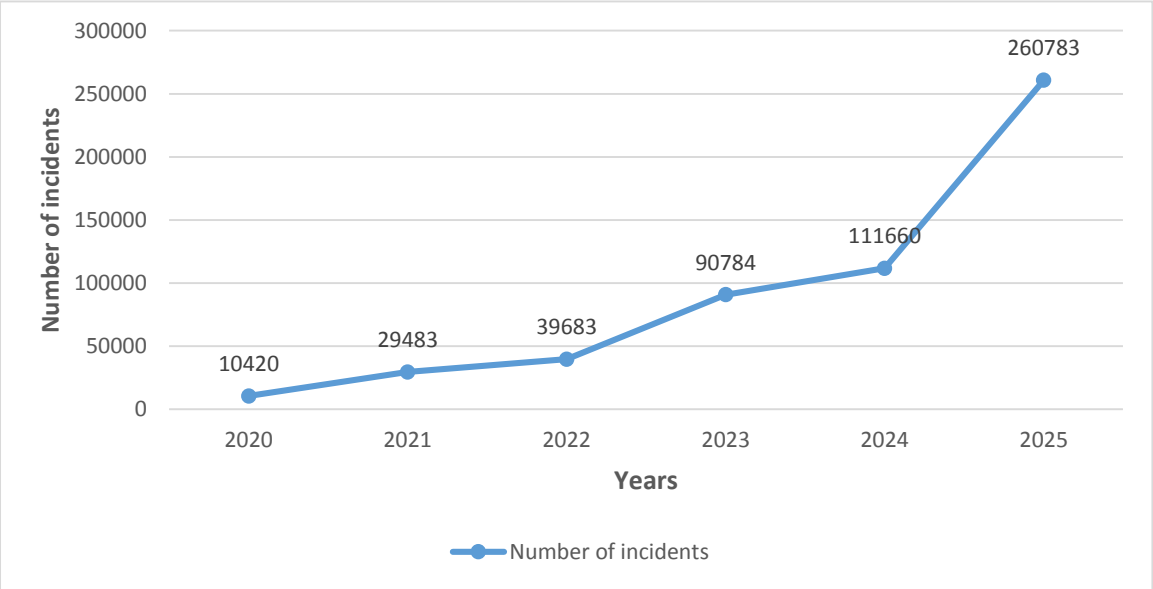

Figure 1. Statistics on cybersecurity incidents in Poland in the years 2020-2025.

Source: Data from the Annual Reports for the years 2020-2025 on the activities of CERT Polska.

The analysis of the number of cybersecurity incidents in Poland in the years 2020-2025 indicates a clear and dynamic upward trend. The data comes from the annual reports of CERT Polska teams and summaries of the national ICT security incident response system (national-level CSIRTs).

During the analyzed period, the number of cybersecurity incidents in Poland increased significantly. This trend results not only from the growing number of actual threats, but also from increasing public awareness, the development of monitoring systems, and the improvement of incident reporting procedures. This indicates the growing importance of cybersecurity as a key element of the functioning of the state and the digital economy.

Based on the data, the dynamics with the year-on-year growth rate were calculated.

$$D = \frac{W_t - W_{t-1}}{W_{t-1}} \cdot 100\% \tag{1}$$

where:

D – dynamics (percentage change),

W_t – value in the current year,

W_{t-1} – value in the previous year.

The year-on-year dynamics are presented in Table 3.

Table 3.

Year-on-year dynamics (in %)

Years	Values
2021/2020	+182,95%
2022/2021	+34,60%
2023/2022	+128,77%
2024/2023	+23,00%
2025/2024	+133,55%

Source: Own elaboration based on data from Annual Reports for the years 2020-2025 on the activities of CERT Polska.

During the analyzed period, a strong upward trend in the number of incidents is visible, characterized by irregular growth rates and sudden spikes. In 2021, there was a very sharp increase of 183%, which may indicate a sudden rise in the number of threats or an improvement in incident detection capabilities. In 2022, growth continued, but at a much slower pace, which may suggest a temporary stabilization of the situation. Another very large increase (129%) occurred in 2023, which may reflect an intensification of cyber threats or changes in reporting methods. The year 2024 showed a relatively small increase, which may indicate a period of temporary slowdown in the growth dynamics. However, in 2025, the number of incidents again increased significantly by 133%. The number of incidents is growing very dynamically, and the alternating periods of moderate growth and sudden spikes are particularly alarming. This may indicate that cyber threats are becoming increasingly serious and more difficult to control, highlighting the need to strengthen cybersecurity systems.

In research conducted by the Author in 2025, the issue of security in selected Polish cities was also examined. The author's own research was carried out in selected cities characterized by a medium and high level of advancement in the implementation of smart city initiatives. MS Excel software was used to process both primary and secondary data, applying basic descriptive statistics methods. The results were also presented graphically in the form of charts based on respondents' answers from the analyzed cities. The research was conducted from January to June 2025 using the survey method. Data collection was carried out online with the use of the Computer Assisted Web Interview (CAWI) technique. In total, 560 correctly completed questionnaires were obtained. The study involved residents of selected cities: Warsaw (85 respondents), Gdansk (79 respondents), Wroclaw (84 respondents), Poznan (80 respondents), Cracow (78 respondents), Lodz (82 respondents), and Rzeszow (72 respondents). The respondents were city residents representing various age groups, including both women and men, diversified in terms of education level and social status. The respondents assessed the level of security based on such elements as: the effectiveness of urban monitoring systems, the protection of digital infrastructure, citizen involvement, and the actions and responses of the relevant services. The following responses were obtained (Figure 2).

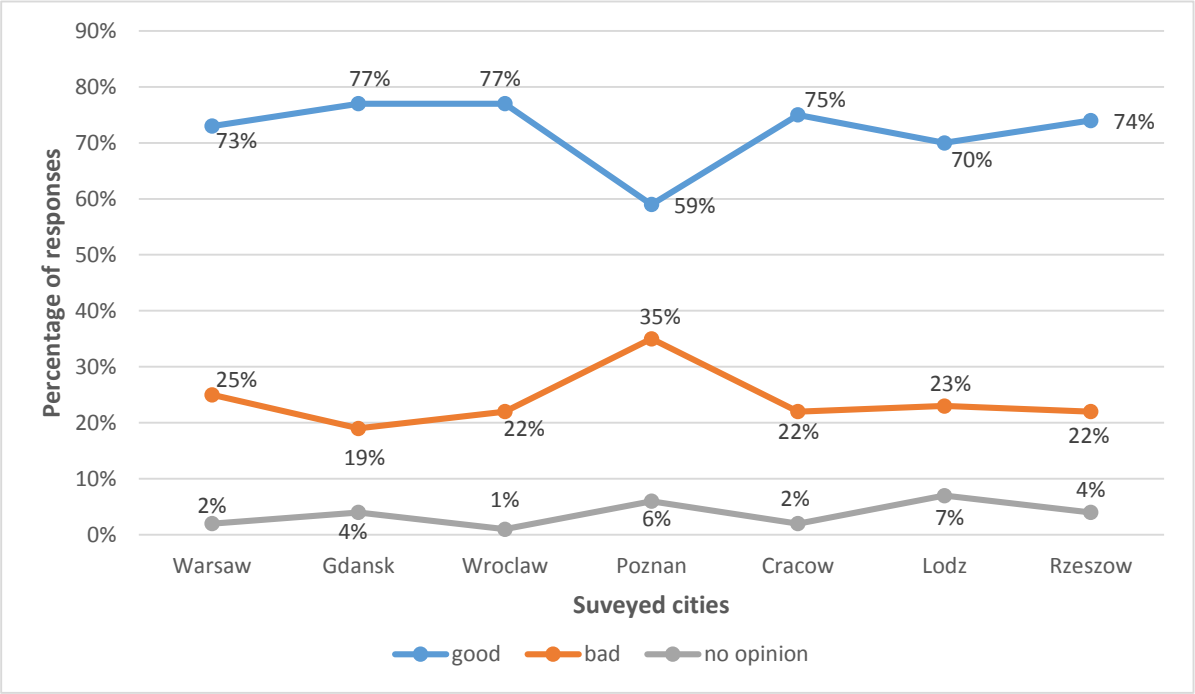

Figure 2. Structure of respondents' responses by city of residence.

Source: Own elaboration based on the survey, n = 560.

The level of safety in the surveyed cities was assessed by respondents as high at approximately 70%, which represents a positive aspect of Smart City functioning. The indicated responses are the subjective opinions of residents of selected cities, but they indicate that appropriate standards are being maintained and that the city demonstrates care for safety in the process of implementing innovative technological solutions.

Raising the level of a city's technological and information development is achieved through the implementation of modern digital technologies, data analysis and processing systems, and intelligent management tools that improve the city's functioning and enhance the quality of life of its residents (Table 4).

Table 4.
Percentage distribution of respondents indicating a high level of responses

City	Level of implementation of Smart City systems	Level of technological and information development in the city
Warsaw	76%	80%
Gdansk	77%	82%
Wroclaw	76%	70%
Poznan	74%	49%
Cracow	77%	53%
Lodz	74%	54%
Rzeszow	79%	57%

Source: Own elaboration based on the survey, n = 560.

Based on the presented data, it can be concluded that a high level of both the use of smart city systems and technological and information development is perceived by respondents across all analyzed cities. The highest values in terms of the use of smart city systems were recorded in Rzeszow (79%), as well as in Gdansk and Cracow (77% each). The remaining cities also show values above 70%, indicating a relatively uniform level of implementation of modern technological solutions in the surveyed cities. In the case of the level of technological and information development, the highest values were recorded in Gdansk (82%) and Warsaw (80%), which indicates a particularly advanced level of digitalization in these cities. Wroclaw achieved 70%, while Rzeszow 57%, Lodz 54%, Cracow 53%, and the lowest result was recorded in Poznan at 49%. This indicates a clearer differentiation between cities in this area compared to the mere use of smart systems.

The comparison of results indicates that city residents positively assess the implementation of modern technologies in urban space as well as the level of digital security. Smart systems and technological and information development are perceived as factors that improve the functioning of the city and contribute to enhancing the quality of life of its residents.

4. Challenges and directions for development

Modern cities should be resident-friendly and responsive to their changing needs. City authorities face significant challenges when seeking to advance technological progress and implement innovative solutions that support urban policies and strategies while remaining beneficial to residents. Digitalization requires a strategic approach rather than merely introducing isolated technologies. It is important to appropriately select available solutions based on existing needs and the resources of the city.

The challenges faced by city authorities are numerous, primarily including a low level of digital maturity in cities, budget constraints, and the need to invest in complex security infrastructure. It is also necessary to mention the insufficient number of specialists in this field, as well as the lack of digital competencies and awareness among residents. Cities also experience difficulties in implementing coherent security standards and face risks associated with the rapid pace of technological development. The implementation of new technologies requires the integration of multiple urban systems. Investments in digital technologies must be properly secured against system vulnerability to cyberattacks. A very important aspect of digitalization concerns legal challenges related to data protection and privacy. Cities must strive to enhance the competencies of public officials and increase citizens' awareness of digital security.

Due to digitalization across all areas of socio-economic functioning, an increase in cyber threats is expected in the future. Possible risks include attacks by foreign states on critical infrastructure, distribution of malicious software to companies and citizens, and an increase in the use of social engineering in fraud schemes targeting individuals. There may also be a rise in campaigns in which criminals use artificial intelligence to generate fake voices and likenesses.

The directions for the development of cities in terms of building resilient and secure urban systems should take into account technological, organizational, and legal aspects. In this context, the need to create integrated security strategies becomes particularly important, as they form the foundation of sustainable and responsible smart city development. Another key development direction is the control and certification of IoT devices, as well as the use of artificial intelligence to detect threats. No changes will be sustainable if residents and city officials are not properly trained and educated about modern forms of cyber threats. Cybersecurity is becoming an essential element of smart city operations, as without adequate resources, the losses resulting from potential breaches may be significantly greater than the benefits of developing a smart city.

5. Summary

In summary, the presented theoretical and practical analyses concerning smart city management and digital security demonstrate that these two areas are closely interconnected. The development of smart cities is associated with the growing importance of protecting digital infrastructure and data. The high level of integration and complexity of technological systems, as well as their significance for the functioning of key urban services, means that digital security is no longer merely an operational support function, but has become a strategic element of management. This encourages the author to conduct further research on the presented topic in

the future. The results of the study enabled the positive verification of the research hypothesis, confirming the validity of the adopted assumptions in light of the collected empirical data and the findings of the analysis. The objective of the article has been achieved through the conducted analyses, which identified the challenges faced by contemporary society regarding digital security. Furthermore, directions for the development of smart city management were indicated in the technological dimension, taking into account cybersecurity aspects. One of the main conclusions is the necessity of implementing a holistic approach to security, covering technological, organizational, and legal aspects. The development of cybersecurity competencies among both specialists and users of urban systems is also of key importance. Digital education, awareness campaigns, and building citizens' awareness are crucial elements in reducing risk and increasing resilience to threats in the digital world. In the context of further development, it is necessary to strengthen cross - sector cooperation, including public - private partnerships, as well as to develop standards and legal regulations adapted to the specific nature of smart cities. It is recommended to conduct research on the use of modern technologies, such as artificial intelligence, to enhance the ability to detect and counter threats. Ensuring digital security is a necessary condition for the sustainable and effective development of smart cities, and its proper consideration in management processes determines the durability and reliability of modern urban functioning. Future efforts should focus on the further integration of cybersecurity issues into the strategic management processes of smart cities. Particular importance should be placed on the development of real-time threat monitoring systems that, through advanced data analytics, support solutions based on artificial intelligence. In the future, it will also be essential to enhance the interoperability of urban systems while maintaining high standards of data protection and residents' privacy. Another important direction is strengthening cities' resilience to cyber incidents through regular security testing, crisis response exercises, and the establishment of municipal security operations centers. Further research should examine the impact of emerging technologies, such as the Internet of Things (IoT), 5G/6G networks, cloud technologies, and Digital Twins, on the level of security and the effectiveness of smart city management. The implementation of these measures may contribute to increasing the resilience of urban infrastructure, improving the quality of public services, and enhancing public trust in digital solutions deployed within urban environments. Future initiatives should therefore concentrate on the close integration of cybersecurity with smart city management processes through the implementation of comprehensive data protection strategies, the development of digital competencies, and the creation of resilient and secure ICT systems. The key challenges remain the growing number of cyber threats, the increasing complexity of smart city infrastructure, and the need to maintain a balance between innovation, residents' privacy protection, and the continuity of public services.

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A LOOP MODEL OF VALUE ALIGNMENT IN ORGANIZATIONAL SYSTEMS

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Purpose: This paper aims to reframe value alignment from a state to be assessed into a property that organizational systems continuously generate and regulate, and to develop a conceptual model of how that production unfolds during the employment relationship.
Design/methodology/approach: The paper is conceptual. It develops the model through an integrative analysis of two prior qualitative studies conducted in Poland — one of employees, one of HR managers — using an abductive procedure that moves iteratively between empirical patterns and systems-theoretical concepts drawn from systems thinking and organizational learning.
Findings: The analysis identifies four recurrent loops. Three are trajectory-generating: a Relational Reinforcement Loop, an Adaptation Erosion Loop, and a Misfit Escalation Loop. The fourth, a Responsiveness Breakdown Loop, is meta-regulatory: it governs whether the organization can still detect and correct the trajectories the others produce. What most decisively shapes an organization's trajectory is not which conditions are present, but whether the system retains the capacity to recognize and respond to what it is generating.
Research limitations/implications: The model is a conceptual reconstruction across two prior qualitative studies; the loops are analytical reconstructions of recurrent dynamics rather than longitudinally observed sequences. Future research should examine the loops empirically across institutional contexts and over time.
Originality/value: The paper reframes value alignment from an entry-stage condition into a problem of organizational detection and response, and proposes responsiveness as a meta-regulatory capacity that determines whether alignment can be sustained.
Keywords: value alignment, person–organization fit, early employment, organizational responsiveness, organizational learning.
Category of the paper: Conceptual paper.

1. Introduction

The literature on person–organization fit rests on a quiet but consequential assumption: that value alignment between an employee and an organization is a state — a condition of congruence that can be assessed, often at entry, and treated as established. Three decades of scholarship have refined how this state is measured, what predicts it, and what follows from it (Chatman, 1989; Cable, DeRue, 2002; Kristof-Brown et al., 2005; Edwards, Cable, 2009). The construct has been remarkably productive. Yet the assumption that organizes it deserves to be questioned, because it carries a hidden cost: it makes alignment something organizations possess rather than something they do, and it places the explanatory burden on individual fit rather than on the organizational arrangements that produce, sustain, or erode alignment over time.

This assumption becomes harder to maintain when one looks at what happens after entry. Employees who began with substantial value congruence can be drawn into trajectories of misfit through nothing they brought with them; organizations that operate with formally adequate alignment practices can still fail to detect misalignment until it has hardened beyond repair (Schneider, 1987; Morrison, Milliken, 2000). Recent reviews of person–organization fit research themselves identify the static, entry-focused framing as a persistent limitation of the field (Kristof-Brown et al., 2023). Treating alignment as a state assessed at one point makes it difficult to explain either of these outcomes. The state-based view also leaves a more uncomfortable possibility unexamined: that misfit may not always be a property of the misfitting employee, but a product of the system in which that employee is embedded — and one that the system may be progressively less able to recognize.

This paper takes that possibility seriously. Its aim is to reframe value alignment from a state to be assessed into a property that organizational systems continuously generate and regulate, and to develop a conceptual model of how that production unfolds during the employment relationship. From this premise, the paper argues that alignment is better understood as a system-level property — something organizations generate, sustain, or fail to regulate through recurrent arrangements that link early experience, interpretation, and organizational response. The model identifies four recurrent loops: three that generate distinct trajectories of alignment, erosion, or escalation, and a fourth — the Responsiveness Breakdown Loop — that operates at a different level, governing whether the organization remains able to detect and act on what the other three produce. This fourth loop carries the paper's central claim: what most decisively shapes an organization's trajectory is not which conditions are present, but whether the system retains the capacity to recognize and respond to what it is generating.

2. Theoretical background

2.1. Person–organization fit and its limits

The study of value alignment has developed largely within the person–organization fit tradition. This body of work established that the compatibility between an employee and an organization — particularly the congruence of their values — is consequential for attitudes and behavior, and it produced a substantial evidence base linking alignment to commitment, satisfaction, and retention (Chatman, 1989; Kristof, 1996; Kristof-Brown et al., 2005). Conceptually, this tradition gave value alignment a clear definition and made it measurable, and that clarity is part of why the construct has been so durable.

Yet the dominant operationalization of fit has tended to treat alignment as a property that can be located and assessed: a degree of congruence held by an employee at a given point. This approach answers the question of whether alignment is present and what follows from it, but it is less equipped to explain how alignment arises, holds, or deteriorates within the organization. The fit tradition has, in this sense, theorized the consequences of alignment more fully than its production.

An important corrective came early, from within the fit tradition itself. Schneider's (1987) attraction–selection–attrition framework argued that organizations are not neutral containers into which fitting or non-fitting individuals are placed; rather, the people who define an organization are themselves the outcome of a process. Individuals are differentially attracted to organizations, differentially selected by them, and differentially retained, so that organizations become more homogeneous over time through the cumulative operation of these three forces. Schneider's framework was significant precisely because it refused to treat fit as a static attribute and located it instead in an ongoing organizational process.

The attraction–selection–attrition framework, however, locates that process at the boundary of the organization — in who is drawn toward it, admitted into it, and retained or lost. It explains how an organization comes to be composed of certain kinds of people, but it says comparatively little about what happens to alignment among those who remain. It does not specify the internal arrangements through which an organization sustains, erodes, or fails to notice alignment once an employee is inside. In particular, it contains no account of how an organization detects that alignment is deteriorating and acts to correct it. Attrition, in Schneider's model, is the mechanism by which misfit is resolved — the misfitting employee leaves — rather than something the organization registers and addresses. More recent attempts to address the temporal dimension of person–environment fit have begun to systematize what little is known about how fit unfolds over time, while at the same time documenting that this dynamic perspective remains underdeveloped relative to static formulations (Vleugels et al., 2023).

This is the specific limit that the present article takes as its point of departure. The fit tradition, including its most process-oriented formulations, has theorized alignment as something to be assessed, or as something resolved through who enters and exits, more fully than as something organizations continuously generate and regulate from within. Explaining that internal generation and regulation requires a different conceptual vocabulary — one capable of describing how organizational arrangements produce alignment, how they reproduce it, and whether they remain able to detect when it is being lost. The following section turns to that vocabulary.

2.2. Systems thinking and organizational learning

Explaining how organizations generate and regulate alignment requires a vocabulary built not around discrete attributes but around relations among elements. Systems thinking provides such a vocabulary. Its central premise is that the behavior of a system arises less from the properties of its individual parts than from the structure of relations connecting them, and that much of this behavior is organized by loops in which an outcome feeds back to alter the conditions that produced it (Senge, 1990; Sterman, 2000). Two kinds of loop are conventionally distinguished. In a reinforcing loop, a change is amplified: the outcome strengthens the conditions that generate it, so that the process gathers force in the same direction. In a balancing loop, a change is counteracted: the outcome activates conditions that work against it, so that the process is dampened or held in check. What makes a loop analytically distinct from a simple sequence of events is recursion — the outcome does not merely conclude the sequence but returns to reshape its starting conditions.

This vocabulary is well suited to the problem identified above. If value alignment is generated within the organization rather than resolved at its boundary, then it is generated through recurrent organizational arrangements in which early experiences, their interpretation, and subsequent organizational responses are linked in self-reinforcing or self-correcting ways. A recursive account makes it possible to ask not only what conditions affect alignment, but how those conditions reproduce themselves — why a supportive beginning can consolidate into a stable trajectory, and why an early difficulty can deepen rather than resolve.

Systems thinking alone, however, describes the form of recursive processes without specifying what allows an organization to act on them. For that, the literature on organizational learning is needed. Argyris and Schön's (1978) distinction between single-loop and double-loop learning is particularly relevant. In single-loop learning, an organization detects a deviation and corrects it within existing assumptions and routines. In double-loop learning, the organization additionally examines and revises the assumptions that generated the deviation in the first place. The capacity for either kind of learning depends on a prior condition: the organization must register that something is occurring. Argyris and Schön's account of organizational defensive routines describes precisely the situation in which this prior condition

fails — arrangements that, often unintentionally, keep problematic information from becoming organizationally visible, so that the system loses access to the very signals it would need in order to correct itself.

This is the conceptual basis for treating the regulation of alignment as a question of organizational learning. An organization does not only generate trajectories of alignment and misfit; it also does, or does not, retain the capacity to detect those trajectories and respond to them. A system in which problematic signals do not become visible is not merely a system with a local problem; it is a system that has lost part of its capacity to learn about itself. This distinction — between generating a trajectory and remaining able to detect it — becomes central to the model developed below, where it differentiates the loop that governs detection and correction from the loops that generate trajectories in the first place.

The two bodies of work are therefore complementary. Systems thinking supplies the form of the model: recursive loops in which outcomes reshape their own conditions. Organizational learning supplies its regulative dimension: the capacity, unevenly distributed across organizations, to detect and correct the trajectories those loops produce. Together they provide the vocabulary that the fit tradition lacks — but they remain general, developed without reference to any particular organizational moment. The model proposed here locates them in a specific and especially revealing setting: the early period of employment.

2.3. Early employment as a formative site

The recursive processes described above can, in principle, operate at any point in the employment relationship. They are, however, especially consequential and especially visible during the early period of employment, and this makes early employment a particularly revealing setting for examining how alignment is generated and regulated.

Research on organizational socialization has long established that early experiences carry disproportionate weight. The initial months in an organization are when role expectations, relational norms, and judgments about belonging take shape, and the patterns formed in this period have lasting consequences for adjustment and retention (Ashforth et al., 2008; Bauer et al., 2007; Louis, 1980). This disproportionate weight is what makes early employment recursively potent: arrangements established at entry do not simply describe a starting state but set conditions that subsequent experience tends to confirm. A small early advantage or difficulty is therefore more likely than a later one to be amplified into a durable trajectory.

Work on sensemaking explains why this is so. During early employment, the organization is still substantially ambiguous to the newcomer, and ambiguity is not interpretively neutral. Newcomers actively read the cues available to them — how they are treated, what is responded to, what is overlooked — and use these cues to construct an operative understanding of what the organization is and what it expects (Maitlis, Christianson, 2014; Weick, 1995). Because this understanding is built from limited evidence, early signals are weighted heavily,

and the interpretation a newcomer forms then shapes how subsequent signals are read. Interpretation, in other words, is itself part of the recursive process: an early reading of the organization conditions later readings.

Psychological contract research adds that these early interpretations are not only descriptive but evaluative. Newcomers assess whether what they encounter is consistent with what was promised or implied, and whether the organization appears reciprocal and credible (Morrison, Robinson, 1997; Rousseau, 1995). Experiences interpreted as breaches do not remain isolated judgments; they alter the basis on which the employee evaluates the organization thereafter. This evaluative dimension is what connects interpretation to trajectory: an early experience read as a violation reorganizes subsequent interpretation around mistrust, while an early experience read as support does the opposite.

Taken together, these literatures establish early employment as a formative site in a specific sense. It is the period in which organizational arrangements, employee interpretation, and organizational responses are most tightly coupled, and in which the resulting loops are still being established rather than already settled. This is what makes early employment not only consequential but analytically tractable: the recursive processes that generate and regulate alignment are, at this stage, close enough to the surface to be reconstructed. The model developed in the following section draws on two qualitative studies of early employment to do precisely that.

3. Method

This article develops a conceptual model of how value alignment and misfit are generated, interpreted, and addressed during early employment. The study is qualitative in its evidentiary basis and abductive in its analytical logic: rather than testing predefined hypotheses, it reconstructs recurrent organizational dynamics by moving iteratively between empirical patterns and systems-theoretical concepts. Its aim is theory development — the articulation of a loop model — grounded in qualitative material rather than the reporting of a new empirical study.

The model integrates evidence from two qualitative studies conducted within a broader multi-stage research programme on value alignment across the employment relationship in Poland. One study addressed the employee perspective; the other addressed the perspective of HR managers. The two studies were designed and analysed separately, each with its own research questions. The present article draws on their findings as the basis for an integrative analysis: it does not re-open the original transcripts or narratives and does not re-code the primary material, but re-examines the already-analysed results of both studies in order to reconstruct the systemic dynamics that connect them. In methodological terms, this is

a secondary analysis of qualitative data — the re-examination of material gathered and analysed for related but distinct purposes.

3.1. Empirical basis: two qualitative studies

The employee perspective derives from a qualitative study of early-tenure employees' critical experiences of organizational adaptation (Paleń-Tondel, 2026). That study used an adapted, questionnaire-based form of the Critical Incident Technique to collect written narrative accounts from employees who had joined their current organization within the preceding twelve months and had completed at least three months of tenure. Participants (N = 300) were recruited through a professional research agency from an established online panel; after exclusion of responses without experiential content, the analysed corpus comprised 457 narratives. The original analysis followed an interpretive, inductive strategy and identified a set of relational interpretive mechanisms through which employees evaluate early organizational signals as affirming or violating the employee–organization relationship.

The HR perspective derives from a companion interview study of how HR managers operationalize, interpret, and respond to value alignment (Paleń-Tondel, n.d.). That study drew on a pool of twelve in-depth interviews with HR managers and HR business partners; the analytic sample was narrowed to the ten interviews conducted with respondents in internally embedded HR roles, with two interviews representing agency-based external recruitment excluded to avoid conflating internally mediated organizational practice with staffing-agency logic. The interviews were conducted in Poland in 2023, in organizations with an established HR function. The analysis followed an abductive qualitative strategy and reconstructed how value alignment is operationalized in everyday practice, how signals of alignment and misfit are interpreted, and what shapes organizational response. The present article draws on the findings of that ten-interview analysis as its account of the organizational, practice-based side of value alignment.

The two studies are not treated as a matched sample. Employees and HR managers were not linked within shared organizations, and the analysis does not compare paired cases. The two sets of findings are used instead as complementary vantage points on the same class of organizational processes: the employee study shows how early experiences are lived and interpreted, while the HR study shows how organizations assess, interpret, and act upon alignment-related signals.

3.2. Rationale for an integrative analysis

Each of the two studies illuminated one side of value alignment in early employment, but neither could capture the recursive relationship between employee experience and organizational response. The employee study showed how interpretation stabilizes into divergent trajectories, yet could not observe the organizational handling that conditions those

trajectories. The HR study showed how organizations operationalize and respond to alignment, yet could not access how those efforts are experienced and interpreted by employees. The systemic dynamics of interest — how experience, interpretation, response, and non-response connect into recurrent patterns — fall in the space between the two studies. An integrative analysis was therefore adopted to reconstruct those dynamics across the two perspectives.

3.3. Analytical procedure

The four-loop model was developed in four steps.

First, the findings of both studies were re-read for recurrent process patterns rather than discrete themes. The guiding question was not which issues appeared in the material, but how an early organizational condition was interpreted and how that interpretation shaped a subsequent trajectory of adaptation, erosion, withdrawal, or failed correction. This re-reading crystallized a processual core common to both perspectives: early experience → interpretation → trajectory. At this stage the unit of analysis was no longer the individual theme or incident, but the recurrent process pattern linking an early condition to its interpretation and downstream consequences.

Second, these patterns were abstracted into higher-order process mechanisms. Four recurrent mechanisms were identified across the combined material: supportive relational conditions that foster safety, adaptive effort, and relational embedding; operational strain that consumes the resources required for adaptation; normatively salient violations that reorganize interpretation around incompatibility and withdrawal; and weak responsiveness that undermines the organization's capacity for correction.

Third, each mechanism was examined for recursive structure. A pattern was treated as a loop only when its downstream consequences did not simply terminate the sequence but altered the conditions under which subsequent experiences would be encountered and interpreted — that is, when the end state increased the likelihood of reproducing or intensifying the originating dynamic. This closure criterion distinguished loops from linear sequences and from static themes, and yielded four loops: a Relational Reinforcement Loop (R1), an Adaptation Erosion Loop (B1), a Misfit Escalation Loop (R2), and a Responsiveness Breakdown Loop (B2).

Fourth, the loops were integrated into a single model organized around the shared processual core. R1, B1, and R2 were classified as trajectory-generating loops, because each describes a distinct pathway through which early experience becomes stabilized into a durable developmental trajectory. B2 was classified as a meta-regulatory loop, because it does not generate a further substantive trajectory but governs whether the system retains the capacity to detect and correct the trajectories it produces. This distinct status of B2 was traceable to the material, in which weak responsiveness consistently operated differently from the other

mechanisms; its conceptualization as meta-regulatory was sharpened through theoretical interpretation rather than derived from the data alone.

3.4. Role of the systems-thinking framework

Systems thinking did not function as an a priori coding template. The analysis did not begin by imposing a loop diagram on the material and populating predetermined slots. The systems perspective operated first as a sensitizing frame, shaping the broader problem formulation: alignment understood as something organizations generate, sustain, erode, or derail, and early employment understood as a systemically consequential phase rather than a discrete onboarding stage. The more specific vocabulary of reinforcement, erosion, escalation, and breakdown entered decisively only after recurrent process patterns had been identified across the two studies. Work on system dynamics (Senge, 1990; Sterman, 2000) and on organizational learning (Argyris, Schön, 1978) thus provided the conceptual language through which already-recognized patterns were interpreted as loops and integrated into a systemic model, rather than an operational instrument that drove the analysis itself.

3.5. Methodological reflexivity

This analytical strategy has a clear strength and a clear limitation. Its strength is integrative: by bringing two independently analysed perspectives into dialogue, it reconstructs recursive dynamics that neither study could capture alone. Its limitation is that it inherits the analytical boundaries of the two primary studies; the model is bounded by what those analyses made visible, and the loops are analytical reconstructions of recurrent dynamics rather than longitudinally observed sequences. The model is therefore offered as a theoretically generative account, to be examined and tested in future research.

4. Findings

The integrative analysis of the two studies indicates that early organizational trajectories are not the cumulative sum of isolated experiences. They are produced by a limited set of recurrent organizational arrangements that link early conditions, their interpretation, and subsequent organizational responses, and that progressively stabilize particular pathways. The analysis identifies four such loops. Three generate distinct trajectories of alignment or misfit; the fourth governs whether the system remains able to correct any trajectory at all. This section presents the four loops in turn and then integrates them into a single model.

4.1. The Relational Reinforcement Loop (R1)

The first loop arises from supportive relational conditions. When newcomers encounter accessible colleagues, coherent guidance, psychologically safe interactions, and managerial responsiveness, they are more likely to interpret the organization as trustworthy, navigable, and worth adapting to. That interpretation increases their willingness to engage, ask questions, tolerate ambiguity, and invest effort in becoming part of the system. Successful adaptation in turn strengthens early relationships, making further support more likely. Through this loop, alignment reproduces itself: support generates safety, safety sustains adaptive effort, adaptive effort strengthens relational embedding, and stronger embedding increases the likelihood of further support. Over time, the loop stabilizes a trajectory in which alignment becomes progressively easier to reproduce, because the system repeatedly confirms the employee's interpretation that it is coherent, responsive, and relationally credible.

Both studies show this pattern. On the employee side, affirming early experiences are described as situations in which support, recognition, and responsiveness made adaptation feel possible and legitimate. On the HR side, the same dynamic appears in accounts emphasizing accessible managers, structured follow-up, and sustained relational support as conditions that stabilize alignment beyond entry. The analytic point is that alignment is not simply detected once it exists; it is progressively produced through recurring relational reinforcement.

4.2. The Adaptation Erosion Loop (B1)

Not every problematic trajectory begins with overt conflict or explicit value violation. A second loop arises from operational strain. Here the early environment is marked by overload, ambiguity, fragmentation, or weakly coordinated support. Rather than enabling adaptation, the system begins by consuming the very resources adaptation requires. As pressure rises, cognitive and relational capacity declines; reduced capacity increases confusion, errors, and friction; and these in turn intensify pressure. The organization does not necessarily produce immediate rejection, but it erodes the conditions under which alignment could otherwise emerge.

This loop matters because it shows that misfit does not always begin as a moral rupture. It can begin as depletion. In such trajectories the organization is not first experienced as violating values, but as difficult to inhabit, difficult to understand, and difficult to keep up with. Over time, persistent strain weakens an employee's ability to make constructive sense of the environment, even in the absence of dramatic conflict.

Both studies show this pattern. Employee narratives describe chaos, absent onboarding, lack of guidance, and settings in which uncertainty was treated as a burden rather than a normal part of entry. On the HR side, the same dynamic appears where alignment is undermined not by hostility but by limits of coordination, diagnostic reach, or managerial bandwidth. The loop

therefore captures a distinct pathway: the erosion of adaptation through systemic strain rather than overt relational violation.

4.3. The Misfit Escalation Loop (R2)

A third loop appears when the early environment crosses from strain into normatively charged disruption. Here employees no longer experience the organization merely as demanding or confusing, but as violating expectations of dignity, fairness, reciprocity, or integrity. Such experiences do more than produce dissatisfaction: they reorganize interpretation. Once value violations become salient, employees withdraw emotionally and relationally from the system, and that withdrawal reduces openness, trust, and willingness to interpret ambiguous signals generously. As relational capacity declines, sensitivity to negative signals rises. Events that might otherwise have been absorbed are instead read as further evidence of incompatibility, and perceived misfit intensifies, making subsequent violations more visible and more consequential. Misfit, in this loop, escalates by changing the interpretive conditions through which organizational life is read.

This is the most overtly destructive of the trajectory-generating loops, because it transforms episodic negative experiences into a self-reinforcing structure of estrangement. Once that structure stabilizes, the organization is no longer encountered as merely uneven or demanding, but as normatively unsafe, and the environment becomes difficult to interpret outside the logic of disrespect, exclusion, or bad faith.

Both studies show this pattern. Employee narratives describe humiliation, mobbing, exclusion, broken promises, symbolic inconsistency, and severe lack of recognition. On the HR side, it appears in accounts of situations that have crossed interpretive thresholds and are no longer treated as local friction, but as consequential breakdowns requiring response. The crucial point is that misfit here does not simply exist; it gains momentum by recursively reorganizing how subsequent signals are interpreted.

4.4. The Responsiveness Breakdown Loop (B2)

The fourth loop differs from the others in kind. It does not generate one more trajectory alongside the others; it governs whether the system remains capable of correcting any trajectory at all. The loop begins when employees signal concern, confusion, overload, exclusion, or value-related tension, and the organization responds weakly, inconsistently, too late, or not at all. In a responsive system, such signals make emerging problems visible and allow corrective action before trajectories harden. In a non-responsive system, the signal does not return as correction; it dissipates.

That dissipation has consequences beyond the unresolved issue itself. When early signals are met with silence, symbolic acknowledgement, delay, defensiveness, or weak follow-through, employees learn something about the system: signalling may not be worth its cost. As willingness to signal declines, fewer signals enter the organization; as fewer signals enter, organizational blindness increases; and as blindness increases, the underlying problem persists and often deepens without being clearly named or addressed. The system does not simply fail to respond on one occasion; it progressively loses the informational conditions required for self-regulation.

This is why responsiveness breakdown is the model's critical failure loop. Strain and value violations can occur in organizations that remain broadly capable of self-correction. But once responsiveness collapses, the system loses the very mechanism through which correction, learning, and stabilization are possible. At that point misfit becomes not only more likely, but harder to detect, harder to interrupt, and harder to reverse.

This loop also explains a paradox visible across both studies: why organizations containing multiple warning signs can later describe problems as if they had appeared suddenly, unexpectedly, or without sufficient evidence. The issue is not the absence of signals. It is that the erosion of responsiveness transforms existing signals into organizational non-knowledge. By that point the problem is no longer only misfit; it is the system's declining ability to know that misfit is occurring.

4.5. One system with multiple trajectories

Considered individually, each loop captures a distinct mechanism through which early experiences are reinforced, eroded, escalated, or left uncorrected. Considered together, they describe not four separate organizational realities but one system with multiple possible trajectories. Figure 1 presents this model.

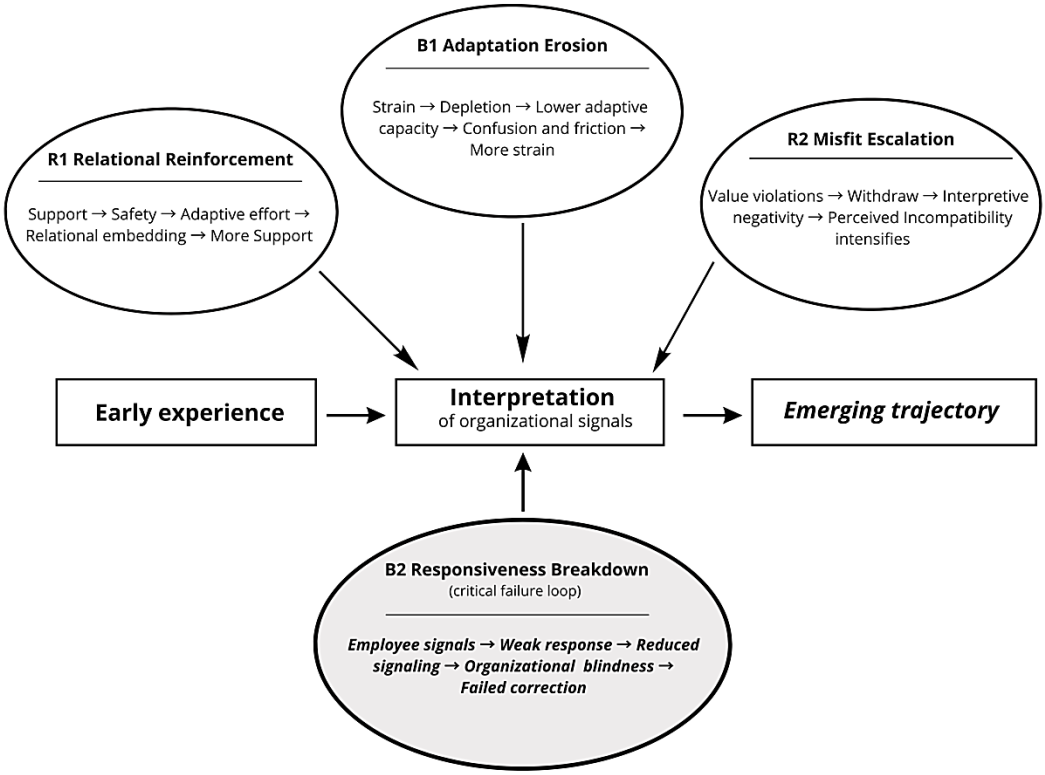

Figure 1. A loop model of value alignment and misfit in early employment.
Source: Author's own work.

At the centre of the model is a process common to all four loops: early experience → interpretation → trajectory. What differs across organizations is not whether employees experience the organization, but how the system processes those experiences. Supportive interactions may be translated, through R1, into safety, adaptive effort, and stronger relational embedding. Workload pressure and fragmentation may instead be translated, through B1, into depletion, confusion, and declining adaptive capacity. Value violations may reorganize interpretation, through R2, around disrespect, exclusion, or incompatibility. In each case, early experiences do not remain isolated events; they enter recurrent structures that make some trajectories progressively more likely to deepen.

This is what makes the four loops a model rather than a typology of conditions. The model does not classify experiences into positive and negative categories; it explains how organizations generate divergent trajectories from early conditions. Alignment emerges when reinforcing relational dynamics become dominant and are not overridden by strain, violation, or failed correction. Misfit emerges when erosive and escalating mechanisms gain traction and shape interpretation more powerfully than support and repair.

Within this model, R1, B1, and R2 are trajectory-generating loops: each describes a distinct pathway through which early organizational membership is progressively confirmed, weakened, or redefined. As Figure 1 indicates, all three operate by feeding into how early

experience is interpreted. B2, the Responsiveness Breakdown Loop, occupies a different position. It is not one more trajectory alongside the others but a meta-regulatory loop: it governs whether the system retains the capacity to correct any trajectory at all. This is why Figure 1 places B2 beneath the interpretive core rather than alongside the other three — it acts on the system's capacity to register and respond to what the other loops produce. Strain and value violations can occur in organizations that remain broadly capable of self-correction; but once responsiveness collapses, the system loses the mechanism through which correction, learning, and stabilization remain possible.

The model therefore consists of three trajectory-generating loops and one critical failure loop. This distinction clarifies that organizations do not fail only because they contain strain or value conflict. They fail more fundamentally when they lose the capacity to process those conditions and act on them.

Seen this way, value alignment is not the product of a single fit mechanism, nor is misfit the consequence of a single disruption. Both are emergent properties of the interplay among reinforcing, erosive, escalating, and corrective processes — emergent in the sense established earlier: properties that arise from the configuration of organizational arrangements rather than from any single trait of the employee. Some systems stabilize alignment because R1 is reinforced while B2 remains intact enough to support correction. Others drift toward erosion because B1 consumes adaptive capacity faster than it is replenished. Others escalate into misfit because R2 reorganizes interpretation around recurring normative injury. And some become especially vulnerable because B2 erodes the organization's capacity to recognize and interrupt the very trajectories it is helping to produce. What the model offers is not the claim that all organizations work alike, but an explanation of why they can generate very different outcomes from seemingly ordinary beginnings.

5. Discussion

5.1. What the model contributes

This article set out to answer a single question: how do organizational systems generate value alignment and misfit during early employment? The loop model is the answer it offers. Rather than treating alignment as a condition to be assessed, the model specifies the organizational arrangements through which alignment and misfit are produced, and it identifies four recurrent loops through which early experiences are stabilized into divergent trajectories.

The model's central claim is not that support, strain, or value violation each matter — the fit and socialization literatures have established that. Its claim is that what most decisively shapes an organization's trajectory is not which of these conditions is present, but whether the

organization retains the capacity to register and act on what it is producing. Three of the loops generate trajectories; the fourth governs whether those trajectories can still be detected and corrected. This distinction reorganizes the explanatory problem. The question shifts from what an organization contains to what an organization can still know about itself.

The sections that follow develop this contribution by situating the model in relation to three bodies of work — research on fit, on early employment and the psychological contract, and on voice, silence, and organizational learning — and then consider what the model contributes methodologically. In each case, the aim is not to restate those literatures but to specify what the loop model adds to them.

5.2. The model and research on fit

The person–organization fit tradition established that value congruence is consequential, and more recent process-oriented work within it has shown that fit is not fixed: it shifts over time and is shaped through ongoing interaction between employees and organizations (Jansen, Kristof-Brown, 2006; Shipp, Jansen, 2011). The loop model is consistent with this process-oriented turn, but it specifies something that process accounts have tended to leave open. Showing that fit varies is not the same as explaining what produces the variation. The model locates that explanation in organizational arrangements: early experiences do not simply accumulate or fluctuate, they are amplified, dampened, or redirected through recurrent loops that stabilize particular trajectories.

This sharpens the contribution of process-oriented fit research in a specific way. The relevant question becomes not only that fit changes, but how an organization generates the conditions under which some trajectories become self-reproducing while others become fragile. A supportive beginning is consequential not because early impressions linger, but because, through R1, it can establish a loop in which support makes further support more likely. A difficult beginning is consequential not because first impressions are negative, but because, through B1 or R2, it can establish a loop in which difficulty reproduces difficulty. The model thus moves the fit literature from documenting variation toward explaining its organizational production.

It also relocates where the explanation of misfit sits. In much fit research, misfit is understood as a property of the employee–organization pairing — a degree of incongruence. The loop model does not deny that incongruence matters, but it treats misfit additionally as something an organization can generate and sustain through its own arrangements, independently of any initial mismatch. An employee who began with substantial value congruence can still be drawn into a misfit trajectory if strain erodes adaptive capacity or if violations reorganize interpretation. Misfit, in this account, is not only a starting condition but a possible organizational product.

5.3. Early employment and the psychological contract

Research on newcomer socialization has long shown that early employment is consequential because it shapes role clarity, relational expectations, and adjustment (Ashforth et al., 2008; Bauer et al., 2007; Louis, 1980). The loop model is consistent with this work but specifies why entry carries such weight. Early employment matters not only because it comes first, but because it is the period in which loops are still being established rather than already settled. An organizational arrangement encountered at entry does not act on a stable relationship; it acts on a relationship whose trajectory is not yet fixed, and it can therefore set conditions that subsequent experience tends to confirm. Entry is consequential, in this account, because it is the point of greatest loop sensitivity — the moment when small differences are most readily amplified into durable pathways.

The model also speaks to psychological contract theory, and reframes one of its central ideas. Psychological contract research has shown that employees interpret organizational action against perceived obligations, and that unmet expectations can be experienced as breach or violation (Morrison, Robinson, 1997; Rousseau, 1995). This work established that the employment relationship is interpretive and normatively charged. The loop model complements it by suggesting that value misfit is not reducible to discrete breach events. A breach, in the model, is rarely self-contained. Through R2, a normatively salient violation can reorganize interpretation itself: it heightens sensitivity to subsequent cues, lowers the threshold at which later events are read as further violations, and draws the employee into an escalating trajectory. What psychological contract research often captures as a discrete episode, the model re-situates within a loop that explains how such episodes become amplified — or, alternatively, interrupted before they harden into durable misfit.

This reframing has a further implication. If misfit escalates through interpretation rather than through the simple accumulation of breaches, then whether a violation hardens into misfit depends heavily on what the organization does next. A breach met with credible response need not initiate an escalating loop; a breach met with silence or symbolic acknowledgement is far more likely to. This is the point at which the analysis of early employment and the psychological contract connects to the model's central concern: organizational responsiveness.

The empirical material on which Loop R2 was reconstructed includes experiences that extend well beyond ordinary value incongruence: humiliation, mobbing, exclusion, broken promises, and the withholding of recognition. Such experiences are addressed in their own right by distinct literatures — workplace bullying (Einarsen et al., 2020), psychological safety (Edmondson, 2018), and organizational injustice (Colquitt et al., 2023) — each providing specific theoretical apparatus for analysing them. The loop model operates at a different level. It describes the regulatory architecture through which experiences of any severity — ordinary perceived incongruence or grave organizational pathology — pass through the same trajectory of interpretation, response, and detection. Severe experiences enter R2 with greater intensity

and can collapse the responsiveness loop more rapidly, but they do not bypass it; they move through it. What the model adds to accounts of bullying, injustice, or psychological safety is therefore not a redefinition of those phenomena, but a description of the conditions under which they become visible to the organization or are lost before correction is possible.

5.4. Responsiveness as a meta-regulatory capacity

The model's central contribution concerns the fourth loop. Research on organizational voice and silence has shown that employees' willingness to raise concerns depends on perceived risk, expected efficacy, and the responsiveness they anticipate, and that organizations can suppress upward communication and thereby lose access to corrective information (Morrison, 2014; Morrison, Milliken, 2000). More recent work consolidates these findings and identifies how accumulated experiences of ignored input can crystallize into a generalized expectation that voice is futile (Morrison, 2023). This work explains why concerns are often not voiced or not heard. The loop model builds directly on it, but extends it from the fate of individual signals to the condition of the system as a whole.

What B2 describes is what happens when weak responsiveness becomes self-reproducing. When early signals are met with silence, delay, or symbolic acknowledgement, employees revise their expectation of efficacy downward and signal less; as fewer signals enter, the organization's view of what it is producing narrows; and the narrowed view makes weak response easier to sustain, because there is less visible reason to respond. Voice and silence research identifies the conditions under which a signal is or is not expressed. The model adds that, once those conditions become recursive, an organization can lose not only particular signals but the standing capacity to register emerging misfit at all. Responsiveness, in this account, is not one moderating condition among others. It is a meta-regulatory capacity: it determines whether the organization can still convert what it produces into something it can act on.

This is also where the model connects to organizational learning theory. Argyris and Schön's (1978) distinction between organizations that detect and correct deviations and those that become trapped in defensive routines describes, in general terms, exactly the vulnerability that B2 specifies in the domain of early employment and value alignment. What B2 identifies is not a failure to respond well on a given occasion, but the progressive erosion of an organization's capacity to know what it is generating. Misfit then persists not only because an underlying problem is unresolved, but because the organization's capacity to learn about itself has itself begun to degrade. A system in this condition does not merely contain misfit; it loses the ability to see it.

This reframing also clarifies what is distinctive about the model's account of misfit. Earlier work on fit has tended to treat misfit as resolved through exit: in the attraction–selection–attrition account, the misfitting employee eventually leaves, and the organization returns toward

homogeneity (Schneider, 1987). The loop model describes a different and more troubling possibility. An organization in responsiveness breakdown does not resolve misfit through attrition so much as fail to register it — it loses the signals that would tell it correction is needed before exit becomes the only remaining outcome. Misfit, in this case, is not cleared from the system; it becomes invisible to it.

The four loops, taken together, therefore support a single theoretical claim. What most decisively distinguishes organizational trajectories is not which conditions — support, strain, or violation — happen to be present, but whether the organization retains the capacity to detect and act on what those conditions are producing. Trajectory-generating loops explain how alignment and misfit form. The meta-regulatory loop explains whether the organization can still do anything about them. This is the sense in which value alignment is best understood not as a condition an organization possesses, but as a property its system continually generates and regulates — or fails to regulate.

If responsiveness is treated as a meta-regulatory capacity, it becomes important to consider how it might be observed and assessed in practice. The model implies several indicators. The first is response speed — the interval between an employee signal (a complaint, a question, a withdrawal cue) and the organization's first acknowledgement, and then between that acknowledgement and substantive action. The second is follow-through — whether initial responses translate into durable change or dissipate after the immediate incident. The third is managerial accessibility — whether employees experience legitimate channels through which signals can travel upward without retaliation or dismissal. The fourth is signal escalation — whether unresolved concerns have routes for review beyond the immediate supervisor, and whether those routes are used. The fifth is retention of signal in the system — whether information acquired through one episode informs later organizational learning, or whether it dissipates once the immediate case is closed. These indicators do not exhaust what responsiveness might mean, but they offer a starting framework for empirical work that could test the four-loop model in specific organizational settings.

5.5. Methodological contribution

The model's contribution is also methodological. It was built by bringing two independently conducted qualitative studies — one of employees, one of HR managers — into a single analysis, not as a matched comparison but as complementary vantage points on the same class of processes. This design has an analytical consequence worth drawing out.

Organizational systems became most visible at the points where the two perspectives did not coincide. From the HR side, an organization could appear to possess routines, channels, and responses for handling alignment-related concerns. From the employee side, those same arrangements could appear delayed, symbolic, fragmented, or effectively absent. This divergence between intended and experienced organizational action echoes a distinction

long recognized in HR research, between practices as designed and practices as enacted and perceived (Nishii et al., 2008; Wright, Boswell, 2002). Treating that discrepancy as a finding rather than as inconsistency to be resolved is what made it possible to see responsiveness as a system property rather than as either a managerial intention or an employee perception. An organization can sincerely intend to respond and still, from the point at which signals actually enter, fail to do so. Neither perspective alone reveals this; it becomes visible only in the gap between them.

This suggests a broader methodological point. Where formal and experiential accounts of the same organization diverge, the divergence need not be treated as measurement error or as one perspective correcting the other. It can be treated as evidence about the organization itself — specifically, about whether what it intends and what it enacts have come apart.

5.6. Limitations and directions for future research

Several limitations bound the claims advanced here, and each points toward further work.

The model is a conceptual contribution developed by reconstruction across two prior qualitative studies. It is therefore bounded by what those studies were designed to capture, and the loops are best understood as analytical reconstructions of recurrent dynamics rather than sequences observed directly. The model specifies how early experiences may be reinforced, eroded, escalated, or left uncorrected, but it does not establish the frequency of these pathways or the conditions under which one rather than another becomes dominant. Establishing that would require research designed to trace loops as they unfold — in particular, longitudinal designs following employees and organizational responses across the early period of employment, able to observe when a given loop begins to consolidate and whether a trajectory can still be redirected once underway.

The two studies were also conducted in a single national context. Institutional conditions plausibly shape both the salience of value-related experiences and the organizational forms through which support, strain, and responsiveness are expressed. The loops are proposed as a general account of how alignment is generated and regulated, but how they operate across institutional and sectoral settings is an empirical question. Comparative research would help establish whether responsiveness breakdown, in particular, takes different forms in organizations facing different labour-market pressures, governance arrangements, or HR architectures.

A further direction concerns the boundary of the model. This article has examined the four loops in early employment, where loop sensitivity is highest. The underlying logic, however, is not in principle confined to entry. Whether the same loops operate later in the employment relationship — and whether responsiveness breakdown is as consequential beyond the early period as within it — is a question the present model raises but does not settle. Examining the

loops across the longer arc of the employment relationship would test how far the account extends.

Finally, the model treats responsiveness as the meta-regulatory capacity that governs whether trajectories can be corrected, but it does not specify what allows some organizations to sustain responsiveness while others lose it. Identifying the conditions that protect or erode this capacity — structural, relational, or managerial — is perhaps the most consequential question the model opens, since it bears directly on whether responsiveness breakdown can be anticipated and interrupted.

6. Summary

This article asked how organizational systems generate value alignment and misfit during early employment, and answered with a model of four loops. Three generate trajectories of alignment, erosion, or escalation. The fourth governs whether the organization can still detect and correct what the others produce. The argument that organizes the model is a single one: what most decisively shapes an organization's trajectory is not which conditions it contains, but whether it retains the capacity to register and act on what it is generating.

This reframes what misfit is. Organizations often locate misfit in the employee — as resistance, oversensitivity, poor adjustment, or a simple absence of fit. The model suggests something less comfortable. Misfit can also be a property the organization produces, and, where responsiveness has broken down, a property it can no longer see. Read this way, a case of misfit is not only a fact about one employee. It can be a signal about the system that generated it — and, in the organizations most at risk, a signal the system has lost the capacity to receive.

This is what an organization misses when it misses misfit. Not only a dissatisfied employee, and not only a relationship that has gone wrong, but evidence about its own condition: evidence of whether it is still able to learn from what it produces. Value alignment, in the end, is not something an organization simply has. It is something a system continually generates and regulates — and the most consequential question is not whether misfit appears, but whether the organization can still recognize it when it does.

The model also carries operational implications for human resource practice, particularly for the early detection of trajectories before they become invisible to the system. For B1 (Adaptation Erosion), organizations can monitor early indicators of workload accumulation and adaptive depletion during the first months of employment — for example, sustained overtime patterns, declining engagement responses on short pulse surveys, or rising frequency of help-seeking that goes unmet. For R2 (Misfit Escalation), early channels for reporting value violations matter most when they are perceived as confidential and credible; complementary diagnostics include skip-level meetings and structured exit interviews focused

specifically on withdrawal patterns rather than on stated reasons alone. For B2 (Responsiveness Breakdown), the most consequential indicators concern the organization's own capacity to respond: time between signal and substantive action, follow-through rates on raised concerns, and periodic review of whether existing channels are merely available or actually used. The point of these diagnostics is not to replace careful interpretation with metrics, but to make visible the dynamics that the model identifies as most easily lost — those occurring at the boundary between what employees signal and what the organization registers.

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PROFILING YOUNG CONSUMERS BASED ON ATTITUDES TOWARD HEALTH, THE ENVIRONMENT AND SUSTAINABILITY OF EDIBLE INSECT-BASED FOODS

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Purpose: The aim of the study was to segment the market of young consumers, represented by members of university students in Poland, into distinct groups characterized by similar attitudes toward health, the environment, and innovative food products containing edible insects.
Design/methodology/approach: The research instrument was an online questionnaire (CAWI). To identify differences among respondents regarding the quantitative variables, the non-hierarchical k-means clustering method was applied. One-way analysis of variance (ANOVA) was used to compare the qualitative consumer characteristics across the resulting clusters.
Findings: The results indicated that the quantitative variables differentiated the study sample into two distinct, homogeneous segments ($p < 0.05$). Cluster 1 was termed "ambivalent and moderately sustainability-oriented". This group consisted of consumers who expressed concern for food safety and environmental sustainability. Cluster 2 was labelled „sceptical and lacking a sustainability orientation". Members of this cluster did not display environmental or health-related attitudes in their food choices and were characterised by negative attitudes towards edible insect foods and low purchase intentions for such products in the future.
Research limitations/implications: The empirical population consists of 947 university students selected through purposive non-probability sampling, so the conclusions cannot be directly generalized to the entire Polish young consumers population.
Practical implications: Understanding the distinct segments of Polish students differentiated by their attitudes towards health, the environment, and alternative sustainable foods based on edible insects, enables the precise tailoring of marketing messages and educational programmes to the needs and values of each group. Such an approach enhances the effectiveness of informational campaigns, supports the development of a positive image for sustainable food products, and contributes to fostering conscious, environmentally responsible consumer choices.
Social implications: The findings may serve as a foundation for public policies aimed at nutritional education and the promotion of sustainable eating habits among the younger generation.

Originality/value: Our study identifies distinct consumer segments based on their attitudes towards health, the environment, and sustainable food. Moreover, this study addresses a significant gap in the literature concerning the younger generation.
Keywords: consumer segmentation, Generation Z, environmental sustainability, sustainable food management**,** segments.
Category of the paper: Research paper.

1. Introduction

Addressing global food challenges necessitates a shift toward more sustainable consumption patterns (van Dijk et al., 2021). The increasing demand for food is driven by population growth, lifestyle changes, urbanization, and rising income levels (Clark et al., 2019; WHO, 2023). These challenges underscore the increasing importance of promoting sustainable food consumption and production (FAO and WHO, 2019). International organizations such as the FAO promote insects as an "underutilized food resource that can help address food security challenges" (FAO, 2021). Entomophagy is considered one of the most promising and environmentally sustainable sources of animal protein (van Huis, Oonincx, 2017; Kim et al., 2021).

Nichifor, Zai, and Timiras (2025) identified several key barriers that hinder the consumption of sustainable food. Among the most significant obstacles are the limited availability of sustainable products, insufficient distribution infrastructure, and unclear labeling, which collectively make it difficult for consumers to make informed choices. High prices of organic goods also represent a substantial barrier, particularly for lower-income households where price sensitivity often outweighs environmental concerns.

Poland presents a distinctive research context due to its rapidly evolving socio-economic landscape, shifting dietary culture, and increasing availability of modern food products. At the same time, the importance of sustainability is gaining traction in public policy and education. However, there remains a notable lack of broad consumer acceptance of novel protein sources, such as edible insects (Mikulec et al., 2024a, 2024b; Orkusz et al., 2020). The interplay between emerging opportunities and enduring challenges creates a compelling context for analyzing consumer segmentation, as well as for identifying both obstacles and viable strategies for the market introduction of sustainable food products.

1.1. Theoretical background

Sustainable food consumption and production lie at the heart of global strategies aimed at mitigating climate change, preserving biodiversity, and preventing the degradation of natural resources (United Nations, 2015). Similarly, a joint report by the FAO and WHO (2019) highlights that a sustainable diet should not only promote individual health but also exert minimal environmental impact, while being culturally acceptable, economically accessible, and socially equitable.

Despite increasing public awareness, the practical implementation of sustainable dietary principles continues to face substantial obstacles, including limited knowledge, strong adherence to traditional eating habits, and low acceptance of novel food products (Ford et al., 2023; Kenny et al., 2023; Nichifor et al., 2025). Studies have consistently identified a significant gap between consumers' stated intentions and their actual behaviors (Borges-Tiago et al., 2024; Gazdecki et al., 2021; Schäufele, Janssen, 2021).

Understanding consumer attitudes toward the health and environmental dimensions of food is therefore essential for developing effective educational and marketing strategies. In this context, consumer segmentation is gaining importance as a tool for identifying groups with distinct values and motivations (Kotler et al., 2021; Schäufele-Elbers, Janssen, 2023; Wedel, Kamakura, 2002). The relevance of segmentation is especially pronounced in light of rapidly shifting consumer preferences and the increasing complexity of the food market, particularly in relation to innovative products. Modern segmentation approaches incorporate a wide range of variables, including demographic, geographic, psychographic, and behavioral factors such as brand loyalty, purchase frequency, and stage of product adoption (McDonald, 2010; Schiffman, Kanuk, 2019). There is also growing interest in latent variables – such as consumer motivations, personal values, and purchase intentions – which offer deeper insights into the complexity of decision-making processes (Su et al., 2019). Contemporary segmentation strategies also increasingly account for psychological factors, including lifestyle and openness to innovation, both of which play a crucial role in shaping purchasing decisions (Gómez-Suárez, Belz, Rennhak, 2022; Rogers, 2003). As a result, segmentation is not only becoming more prominent in corporate marketing strategies but is also emerging as an essential component of effective consumer relationship management.

In recent years, a growing number of studies have employed segmentation techniques to examine the diverse attitudes of consumers toward health, environmental protection, sustainable food, and innovative products (Camanzi et al., 2024; Mancini, Antonioli, 2024; Marette, Roosen, 2023; Schäufele-Elbers, Janssen, 2023). The literature includes both traditional typological approaches and more targeted models, such as segmentation based on the LOHAS (Lifestyle of Health and Sustainability) concept. Some studies go beyond self-reported data by incorporating panel data on actual purchasing behavior, which allows for

a more nuanced analysis of the discrepancies between consumer attitudes and real-world behaviors (Schäufele-Elbers, Janssen, 2023). A particularly dynamic area of segmentation research concerns perceptions of alternative food sources, including entomophagy. Kamenidou et al. (2023) identified four consumer segments within the Greek Generation Z population: "Future potential insect consumers", the "Rejecters", the "Disgusted, prefer to starve", and the "Inconsistent". Despite generally low levels of food neophobia, members of Generation Z remain reluctant to embrace insect-based products. Valesi, Andreini and Pedeliento (2024), using the Theory of Planned Behavior (TPB) as a framework, identified three segments among Italian consumers: insect-progressives (hedonists open to new flavors), insect-avoidants (driven by health and environmental concerns), and insect-rejectors (firm opponents).

In summary, contemporary segmentation research reveals the complex structure of the sustainable consumption market. A segmented understanding of the market enables more targeted and efficient efforts to foster sustainable dietary habits across society. The rationale for conducting a pilot study in Poland stems from the need to understand the specific characteristics of Polish consumers, particularly young ones, as their attitudes will play a critical role in shaping future food trends. Young people are among the fastest adopters of change, demonstrating both high receptivity to innovation and strong environmental awareness. Therefore, examining the attitudes of Polish Generation Z toward health, the environment, and insect-based foods holds significant practical and academic value. Insights generated by this research can inform the development of educational and marketing strategies aimed at encouraging health-conscious and environmentally responsible food choices among young Poles, including greater acceptance of sustainable insect-based products.

This study offers a novel perspective on young consumers the context of health attitudes, environmental attitudes and interest in sustainable with edible insect foods. The aim of the study was to segment the market of young consumers, represented by members of university students in Poland, into distinct groups characterized by similar attitudes toward health, the environment, and innovative food products containing edible insects.

The research hypothesis proposed that students are heterogeneous in terms of their health-related attitudes, environmental concerns, and perceptions of insect-based novel foods. Potential segmentation factors include gender, field of study, place of residence, perceived material status, orientation towards pleasure, convenience and rapid meal preparation, attention to the consumption of high-nutritional-value foods, appreciation of regional culinary traditions, as well as high health consciousness and physical activity levels.

2. Methods

2.1. Data collection and sample characteristics

The segmentation of young consumers was based on data collected through a survey conducted among students enrolled in higher education institutions in Poland representing Generation Z. The study protocol was reviewed and approved by the University Ethics Committee for Scientific Research at the Krakow University of Economics (approval no. KEBN/71/0044/D24/2023). A non-probability purposive sampling method was employed to select participants (N = 947). All respondents provided informed and voluntary consent to participate in the study and confirmed their awareness of potential risks associated with participation in a Computer-Assisted Web Interview (CAWI).

The segmentation of young consumers was based on data collected through a study conducted among students enrolled in higher education institutions in Poland.

The research instrument was an online questionnaire administered via a CAWI platform, consisting of two main sections. The first section included items related to quantitative variables (see Table 1), specifically:

- Health awareness / attitudes toward organic food – HA (Kornher et al., 2019).
- Concerns for food safety – CFS (Mikulec et al., 2024b).
- Concerns for environmental sustainability – CES (Mikulec et al., 2024b).
- Food neophobia – FN (Pliner, Hobden, 1992).
- Attitudes toward sustainable food containing edible insects – ASF (Wang et al., 2013).
- Purchase intention for insect-based food – ISF (Kornher et al., 2019; Lee et al., 2010).

The second section of the questionnaire comprised a demographic and lifestyle profile, including variables such as gender, field of study, place of residence, self-assessed financial situation, and lifestyle indicators. These indicators covered pleasure orientation, convenience and speed in meal preparation, attention to the nutritional quality of food, appreciation for regional culinary traditions, self-perceived health consciousness, and level of physical activity (Platta et al., 2024a).

During the survey, the respondent expressed his or her level of approval or disapproval of all the posted items using a 5-point Likert scale, where the values means: 1 - „definitely no", 2 - „no", 3 - „I do not know, I have no opinion", 4 - „yes", 5 - „definitely yes" (Likert, 1932).

Although Likert-scale items are strictly ordinal in nature, composite scores derived from multi-item constructs were used in the clustering procedure. Following common practice in social science and consumer behavior research, aggregated scale scores are treated as approximately interval-level variables, which allows the application of distance-based clustering methods such as k-means.

Table 1 presents the characteristics of the sample in terms of gender, place of residence, and financial situation. The study included 947 participants, of whom 59.98% identified as female. The largest groups of respondents were enrolled in engineering and technical programs (41.08%) and social sciences (40.34%). The most represented backgrounds were rural areas (36.85%) and medium-sized cities with populations between 150,000 and 500,000 residents (21.96%). Regarding financial self-assessment, the majority rated their situation as good (53.01%) or very good (20.91%).

Table 1.
Sample characteristics

Variable	Category	n	%
Gender	Female	568	59.98
	Male	379	40.02
Field of Study	Engineering and Technical Sciences	389	41.08
	Social Sciences	382	40.34
	Medical and Health Sciences	74	7.81
	Natural and Physical Sciences	48	5.07
	Humanities	30	3.17
	Agricultural Sciences	24	2.53
Place of Residence	Rural area	349	36.85
	Town with population up to 50,000	167	17.63
	Town with population from 50,000 to 150,000	157	16.58
	City with population from 150,000 to 500,000	208	21.96
	City with population over 500,000	66	6.97
Financial Situation	Insufficient	27	2.85
	Adequate	215	22.70
	Good	502	53.01
	Very good	198	20.91
	Particularly high economic status	5	0.53

Source: own elaboration based on survey results.

An analysis of respondents' lifestyle characteristics (Table 2) reveals that a clear majority identified themselves as pleasure-oriented individuals (81.84% responded "strongly agree" or "rather agree") and as those who value convenience and speed in meal preparation (86.59%). Additionally, a substantial proportion reported a high level of health consciousness (65.68%) and indicated that they pay attention to the nutritional value of the food they consume (63.79%). Approximately half of the participants described themselves as physically active individuals (51.85%) and as appreciative of the culinary traditions of their region of origin.

Table 2.
Lifestyle characteristics of respondents

Statement	Response	n	%
I am a person pleasure oriented	Strongly agree	254	26.82
	Rather agree	521	55.02
	Don't know / No opinion	109	11.51
	Rather disagree	45	4.75
	Strongly disagree	18	1.90

Cont. table 2.

I am a person who values convenience and speed of meal preparation	Strongly agree	369	38.97
	Rather agree	451	47.62
	Don't know / No opinion	61	6.44
	Rather disagree	46	4.86
	Strongly disagree	20	2.11
I am a person who pays attention to the consumption of food with high nutritional value	Strongly agree	235	24.82
	Rather agree	369	38.97
	Don't know / No opinion	160	16.90
	Rather disagree	152	16.05
	Strongly disagree	31	3.27
I am a person who values the culinary traditions of the region origin	Strongly agree	170	17.95
	Rather agree	297	31.36
	Don't know / No opinion	181	19.11
	Rather disagree	215	22.70
	Strongly disagree	84	8.87
I am a person who with high health consciousness	Strongly agree	205	21.65
	Rather agree	417	44.03
	Don't know / No opinion	180	19.01
	Rather disagree	119	12.57
	Strongly disagree	26	2.75
I am a person with high physical activity	Strongly agree	180	19.01
	Rather agree	311	32.84
	Don't know / No opinion	149	15.73
	Rather disagree	239	25.24
	Strongly disagree	68	7.18

Source: own elaboration based on survey results.

2.2. Statistical approach

The collected empirical data were subjected to statistical analysis using the following methods:

- Scale reliability analysis was conducted based on Cronbach's alpha coefficients (Chan, Idris, 2017) and Average Variance Extracted (AVE). These methods were employed to assess the reliability of the quantitative variable scales used in the research instrument. A minimum Cronbach's alpha value greater than 0.7 was adopted, in accordance with Nunnally's criterion (Panayides, 2013, p. 689).
- Cluster analysis was performed using the non-hierarchical k-means clustering method. This analysis was used to identify differences among respondents with respect to attitudes toward health, the environment, and the sustainability of insect-based foods. The grouping variables were quantitative in nature. To compare consumer-related characteristics (qualitative variables) across the resulting clusters, a one-way analysis of variance (ANOVA) was applied.

A significance level of $p = 0.05$ was assumed for all statistical tests. The analyses were carried out using IBM SPSS Statistics 26 and Statistica version 13.3.

3. Results

3.1. Attitude towards health and nutrition and natural foods

3.1.1. The results of principal component analysis

As presented in Table 3, all measurement scales used in the study exhibited high internal consistency, exceeding the commonly accepted threshold for reliability (Cronbach's $\alpha > 0.7$). The values of Average Variance Extracted (AVE) were also above the recommended cutoff of 0.5 (Shrestha, 2021, pp. 5-6).

Table 3.
Measurement model: reliability and AVE

Construct	Items	Cronbach's α	AVE
Health Awareness Scale (HA)	5	0.82	0.58
Concern for Food Safety Scale (CFS)	4	0.92	0.81
Concern for Environmental Sustainability Scale (CES)	2	0.88	0.89
Food Neophobia Scale (FN)	10	0.80	0.64
Attitudes Toward Sustainable Food Containing Edible Insects Scale (ASF)	4	0.95	0.88
Purchase Intention for Insect-Based Food Scale (ISF)	4	0.91	0.80

Source: own elaboration based on survey results.

To identify internally homogeneous consumer groups based on six quantitative variables (HA, CFS, CES, FN, ASF, ISF), a non-hierarchical k-means cluster analysis was conducted. The results of the ANOVA (Table 4) indicated that these variables significantly differentiated the sample into two distinct clusters ($p < 0.05$). Cluster centers were established based on mean values for each of the six variables. The number of clusters (k) was determined based on an iterative procedure. Solutions with k ranging from 2 to 4 were evaluated and compared in terms of cluster interpretability, group separation, and practical relevance. The two-cluster solution was selected as it provided the most meaningful and clearly distinguishable consumer segments. Table 5 presents the profiles of these consumer segments. Further analysis (Table 6) revealed that variables such as place of residence, pleasure orientation, importance of convenience and speed of meal preparation, valuation of regional culinary traditions, and health consciousness significantly differentiated participants between clusters ($p < 0.05$).

3.1.2. Cluster Profiles

Cluster 1 (49.52% of the sample): "Ambivalent and Moderately Sustainability-Oriented". This group consisted of consumers who expressed moderate concern for food safety ($M = 3.96 \pm 0.79$) and environmental sustainability ($M=3.88 \pm 0.77$). They reported neutral attitudes toward health ($M = 3.23 \pm 0.99$) and limited positive attitudes toward insect-based food alternatives ($M = 3.32 \pm 0.88$). Respondents belonging to this group exhibited a low level of food neophobia (mean score: 1.93 ± 0.80), while the majority expressed an ambivalent attitude toward the purchase of insect-based food products (Table 5). This cluster was predominantly composed of residents from rural areas (15.52%) and medium-sized cities with

populations ranging from 150,000 to 500,000 (12.57%) (Table 7). In this cluster, strongly agree attitudes in the area of lifestyle variables accounted for a small percentage of all respondents: health consciousness - 11.72%, pleasure orientation - 13.62%, valuing regional culinary traditions - 7.29%. In contrast, 20.49% valued convenience and speed of meal preparation.

Cluster 2 (50.48% of the sample): "Skeptical and Non-Sustainability-Oriented" Members of this cluster did not exhibit environmentally or health-oriented dietary concerns (M = 2 and M = 3, respectively). They displayed predominantly negative attitudes toward insect-based food (M = 1.56 ± 0.74) and reported very low purchase intentions (M = 1.24 ± 0.53). Their average food neophobia was higher compared to Cluster 1 (M = 2.56 ± 1.02) (Table 5). This group predominantly included rural residents (21.33%). Strong attitudes towards lifestyle were represented by a small percentage of respondents belonging to this cluster: high health consciousness - 9.93%, orientation towards pleasure - 13.20%, appreciation of convenience and speed of food preparation - 18.48%, appreciation of regional culinary traditions - 10.67%.

Table 4.
Comparison of quantitative variables between consumer segments

Variable	SS (Between)	df (Between)	SS (Within)	df (Within)	F	*p*-value
HA	4.67	1	952.96	945	4.63	0.03
CFS	556.18	1	871.61	945	603.02	< 0.001
CES	628.56	1	745.70	945	796.55	< 0.001
FN	92.98	1	803.70	945	109.33	< 0.001
ASF	734.33	1	625.89	945	1108.74	< 0.001
ISF	720.36	1	771.11	945	882.80	< 0.001

Source: own elaboration based on survey results.

Table 5.
Mean scores of quantitative variables by cluster

Segmenting Variable	Clusters			
	1 N = 469		2 N = 478	
	X śr. ± SD	M	X śr. ± SD	M
HA	3.23 ± 0.99	3	3.09 ± 1.01	3
CFS	3.96 ± 0.79	4	2.43 ± 1.10	3
CES	3.88 ± 0.77	4	2.25 ± 0.99	2
FN	1.94 ± 0.80	2	2.56 ± 1.02	2
ASF	3.32 ± 0.88	3	1.56 ± 0.74	1
ISF	2.98 ± 1.17	3	1.24 ± 0.53	1

Source: own elaboration based on survey results.

Table 6.
Impact of qualitative variables on cluster membership

Variable	SS (Effect)	df	MS (Effect)	SS (Error)	df	MS (Error)	F	*p*-value
Gender	0.48	1	0.48	226.84	945	0.24	2.01	0.16
Field of Study	0.06	1	0.06	2246.59	945	2.38	0.03	0.87
Place of Residence	29.81	1	29.81	1714.14	945	1.81	16.43	< 0.001
Self-assessed financial situation	0.33	1	0.33	536.74	945	0.57	0.57	0.45

Cont. table 6.

Pleasure Orientation	3.68	1	3.68	701.32	945	0.74	4.96	0.03
Convenience and Speed of Meal Preparation	5.10	1	5.10	763.20	945	0.81	6.31	0.01
Attention to Nutritional Value	3.92	1	3.92	1168.59	945	1.24	3.17	0.08
Valuing Regional Culinary Traditions	7.38	1	7.38	1452.50	945	1.54	4.80	0.03
High Health Consciousness	8.22	1	8.22	997.36	945	1.06	7.79	0.01
High Physical Activity	0.13	1	0.13	1449.35	945	1.53	0.09	0.77

Source: own elaboration based on survey results.

Table 7.

Cluster composition based on statistically significant differentiating variables

Variable	Cluster 1	Cluster 2
Distribution of Respondents Across Clusters in Relation to the Full Sample (%)		
Place of Residence		
Village	15.52	21.33
Town (≤ 50,000 inhabitants)	8.98	8.66
Town (50,000-150,000 inhabitants)	8.03	8.55
City (150,000-500,000 inhabitants)	12.57	9.40
City (> 500,000 inhabitants)	4.44	2.53
Pleasure Orientation		
Strongly disagree	0.74	1.16
Rather disagree	1.27	3.48
Don't know / No opinion	5.70	5.81
Rather agree	28.19	26.82
Strongly agree	13.62	13.20
Valuing Convenience and Speed of Meal Preparation		
Strongly disagree	0.53	1.58
Rather disagree	2.22	2.64
Don't know / No opinion	2.64	3.80
Rather agree	23.65	23.97
Strongly agree	20.49	18.48
Valuing Regional Culinary Traditions		
Strongly disagree	5.81	3.06
Rather disagree	10.14	12.57
Don't know / No opinion	10.24	8.87
Rather agree	16.05	15.31
Strongly agree	7.29	10.67
High Health Consciousness		
Strongly disagree	0.84	1.90
Rather disagree	5.49	7.07
Don't know / No opinion	8.76	10.24
Rather agree	22.70	21.33
Strongly agree	11.72	9.93

Source: own elaboration based on survey results.

4. Discussion

Young consumers are widely recognized as a key demographic shaping future market trends, with projections suggesting they will account for approximately 30% of global purchasing power (Nadkarni, Mittal, 2022). This generational cohort is often characterized by a growing concern for both health and environmental issues, which increasingly influences their

food-related behaviors, although not always in a consistent or linear manner (Ghazali et al., 2021; Halicka et al., 2025; Ipsos, 2025). Furthermore, young consumers from Generation Z displays substantial internal diversity, shaped by cultural, social, and economic variables (Su et al., 2019). Scholarly literature highlights the importance of critically approaching generational typologies, cautioning against overgeneralization that may lead to cognitive bias and ineffective market strategies (Khan, 2022).

The present study identified two statistically distinct and internally homogeneous clusters within young consumers in Poland, differing in their attitudes toward health, the environment, and the sustainability of edible insect-based food products. Contrary to prior segmentation models, which frequently distinguish between highly engaged, moderately engaged, and disengaged or skeptical consumers, no segment demonstrating strong pro-health and pro-environmental commitment emerged in our analysis. Previous studies have yielded more differentiated segmentation structures. For instance, Gazdecki et al. (2021) identified three consumer profiles: "Doers", who actively engage in sustainable practices despite limited knowledge; "Conscious" individuals, who are well-informed yet experience an attitude–behavior gap; and "Reluctant" consumers, characterized by low engagement and low awareness. Similarly et al. (2022) proposed three clusters within the Hungarian Gen Z population: personas aligning with the LOHAS (Lifestyles of Health and Sustainability) profile, those with potential alignment, and those unaligned. Maťová et al. (2024) distinguished four pro-environmental segments among Slovak consumers: Indifferent Greens, Economical Greens, Engaged Greens, and Image-Conscious Greens. Lotko et al. (2025) identified three groups based on awareness and attitudes toward sustainable products, ranging from skeptics to informed enthusiasts. Funk, Sütterlin and Siegrist (2021), analyzing Swiss consumers, developed a six-segment typology based on environmentally oriented dietary behavior: meat- and fish-eaters, origin-focused food savers, ambiguous consumers, food waste reducing sharers, renouncement aversives, and consequent pro-environmental consumers. Several segmentation frameworks emphasize a dichotomy between progressive segments, characterized by openness to ecological innovation, and conservative or indifferent ones, oriented toward traditional food choices (Legendre, 2021; Junges et al., 2021). The progressive group tends to exhibit lower food neophobia and greater receptiveness to knowledge, whereas the conservative segment is marked by skepticism and a strong attachment to habitual consumption patterns. According to the literature, the prevailing ambivalence among Polish students regarding health and environmental concerns in the context of readiness to consume edible insects (Mikulec et al., 2024b) may increase their susceptibility to persuasion and external influence. Therefore, market segmentation and consumer profiling should be considered when designing strategies to promote the consumption of edible insects as part of a global strategy for sustainable food systems (Florença et al., 2022).

Conclusions drawn from segmenting the market of young consumers, represented by members of Polish students, into distinct groups characterised by similar attitudes towards health, the environment and innovative food products containing edible insects refer to only one part of the examined reality. From a practical perspective, the results offer actionable insights for marketers and policymakers aiming to encourage sustainable dietary changes among students. Recognizing the heterogeneity within this demographic allows for more precisely tailored marketing messages and educational interventions that align with the specific needs and values of each segment. Additionally, the results may inform public policy initiatives targeting nutrition education and the promotion of sustainable eating habits among students at Polish universities. Educational institutions, NGOs, and grassroots campaigns have a key role to play in fostering awareness of alternative food sources, including insect-based products.

The research has certain limitations. Despite the large size of the study group, the results obtained are not representative and cannot be generalised to the population of students in Poland.

5. Summary

This study identifies two distinct consumer segments based on attitudes toward health, environmental sustainability, and insect-based foods: the "ambivalent and moderately sustainability-oriented" and the "skeptical and non-sustainability-oriented". These findings provide valuable theoretical contributions to the field of sustainable food consumption and enhance the existing body of knowledge in consumer behavior theory and sustainable marketing. Furthermore, the study fills a significant gap in the literature concerning Polish consumers (students). Our findings highlight the necessity of designing and implementing educational efforts that promote pro-health and pro-environmental attitudes while building a favorable image of sustainable food products. Based on the study, we formulated recommendations for future studies, which can be focused on analyzing the topic much more accurately.

The results suggest that communication and educational strategies promoting insect-based foods should be tailored to the characteristics of the identified consumer segments.

For Cluster 1 ("Ambivalent and Moderately Sustainability-Oriented"), communication efforts should focus on increasing familiarity with insect-based foods and reinforcing their environmental and food safety benefits. Given the relatively positive attitudes toward environmental sustainability (M = 3.88) and moderate acceptance of insect-based foods (M = 3.32), this group appears receptive to factual information emphasizing the ecological advantages of insect production, product quality, safety standards, and nutritional value.

Product promotion strategies could also highlight convenience and ease of preparation, as convenience-oriented attitudes were relatively common within this segment.

In contrast, for Cluster 2 ("Skeptical and Non-Sustainability-Oriented"), direct promotion of insect-based products may be less effective due to the very low levels of acceptance (M = 1.56), purchase intention (M = 1.24), and higher food neophobia (M = 2.56). For this segment, educational initiatives should first focus on reducing psychological barriers associated with novel foods, increasing trust in food safety, and improving awareness of the production process. Exposure-based communication strategies, including product tasting events, educational campaigns, and transparent information about product origin and safety, may help gradually reduce resistance toward insect-based foods.

These findings indicate that a one-size-fits-all approach is unlikely to be effective. Instead, differentiated communication strategies should be developed for consumer segments characterized by different levels of sustainability orientation, food neophobia, and willingness to purchase insect-based food products.

The research has certain limitations. Despite the large size of the study group, the results obtained are not representative and cannot be generalised to the population of students in Poland.

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NEW ARCHITECTURE OF RELATIONAL QUALITY MANAGEMENT: THE INTEGRATED BEHAVIORAL MODEL (IRSQ)

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Purpose: The property insurance sector, classified in organization theory as a domain of "credence goods", is characterized by high levels of information and perceptual asymmetry. Traditional quality management concepts derived from the TQM paradigm exhibit significant limitations when confronted with the behavioral aspects of consumer decision-making. The objective of this study is to address this research gap by developing and validating an original model of Integrated Relational Service Quality (IRSQ), which enables the measurable identification and mitigation of quality gaps within financial market entities.
Methodology: The research analysis is based on the author's methodological evolution: from the adaptation of the SERVQUAL model and the construction of the original Customer Service Quality Index (WJOK) to the target IRSQ model. The empirical component comprises a cross-sectional study conducted in 2023 on a sample of 658 property insurance clients in Poland and the USA. The research process utilizes advanced statistical measures to quantify quality gaps.
Findings: The research demonstrated that personnel professionalism, information reliability, and the timeliness of claims processing are the primary determinants of quality. The IRSQ model, representing the culmination of the author's methodological evolution, effectively integrates rigorous management procedures with behavioral feedback loops. By shifting the paradigm from static assessment to relational management, the model provides a pioneering framework for mitigating information asymmetry. The findings indicate that trust is a dynamic structural resource, and its systematic management via the IRSQ model constitutes a fundamental pillar of competitive advantage in the public trust service sector.
Research context: The study focuses on the property insurance market, necessitating caution when generalizing conclusions to other financial market segments. A further challenge is the dynamic volatility of client expectations, driven by psychological mechanisms such as information framing.
Social implications: The insurance sector acts as a guarantor of financial security. High service quality, as measured by the IRSQ model, directly translates into the reduction of psychological tension (fear of risk) and the strengthening of social trust in financial institutions.
Practical implications: Quality management should be based on feedback loops (PDCA logic), where customer satisfaction is not the end of the process but rather input data for the redefinition of service standards. It is recommended to implement IRSQ diagnostic sheets to continuously optimize service and eliminate perceptual asymmetry.

Originality/value: The study introduces a pioneering architectural framework for relational quality management. By conceptualizing the IRSQ model as a strategic bridge between behavioral consumer insights and organizational decision-making, this work transcends traditional static models. The proposed Integrated Behavioral Model redefines the service delivery process, synthesizing SERVQUAL and WJOK methodologies into a robust diagnostic instrument to institutionalize trust-based management.
Keywords: service quality, IRSQ, property insurance, perceptual asymmetry, customer trust.
Article category: Research paper.
JEL classification: G22, M10, D80, L84.

1. Introduction

In current times, amidst steadily increasing competition, the primary objective of every insurance company is to meet and even exceed client expectations, which enables the creation of strong relationships between the insurer and their client (cf. Alhuwitat, Abujarad, Salem, 2017), thereby ensuring customer loyalty. This constitutes the main goal of Customer Relationship Management (CRM) (cf. Asgarpourza, Hamid, Mousavido, Jamshidiz, 2013).

The products and services of a given insurance company should be of the highest possible quality, and quality ought to constitute a constant system of monitoring, control, and improvement. In the property insurance services industry, high quality is an immanent service feature that determines the retention of old clients (recipients) and the acquisition of new ones (cf. Meidute-Kavaliauskiene, Aranskis, Litvinenko, 2014). Property insurance services are a specific sector that requires the highest quality of service.

Insurance company employees must possess highly specific and above-standard competencies that significantly exceed the highest quality requirements for insurance services in the insurance industry (cf. Wiluk, 2016). In the case of the insurance sector, every stage of the service delivery process is extremely important for the financial security of both the service provider and the service recipient, and requires systematic and continuous monitoring by management (cf. Júnior, Souki, Filho, 2008). Any error by an insurance company employee, as well as by persons (insurance agents and brokers) cooperating with a given company, may lead to a loss of trust and financial resources, and the client may lose confidence or even fail to obtain the expected benefit and/or compensation for the damage incurred under the insurance contract. Services provided by insurance intermediaries must be of the highest quality, timely, i.e., adapted to the individual, specific needs of the clients of property insurance companies (cf. Otsetova, Enimanev, 2014). Clients continuously exert pressure for high quality of services provided by insurance intermediaries. According to Imai's (1986) concept of quality, which defines it as "everything that can be improved", service providers must constantly undertake actions to improve quality.

One of the methods for assessing and improving service quality is the adoption of a proprietary method for service quality improvement aimed at assessing quality from the client's point of view, because listening to the voice of the customer is a way to analyze and improve quality. An important aspect of the research is to determine which factors have a decisive influence on the level of property insurance service quality improvement, and subsequently to assess customer satisfaction in relation to the level of realization of these factors. This study aims to evaluate and compare the quality of services provided by insurance companies in Poland and the United States of America (USA) conducting insurance activities in Division II (miscellaneous personal and property insurance), utilizing a proprietary method of service quality improvement. The insurance sector under study makes every effort to constantly raise the level of customer service quality in order to meet high customer requirements, because in the currently globalizing financial market, including the insurance market, managers realize that the level of service quality is a significant factor influencing the financial situation of an insurance company – which became the cause for undertaking this type of research.

Building upon this premise, the present study introduces a significant contribution to management theory through a unique synthesis of established SERVQUAL and WJOK methodologies within the proprietary Integrated Relational Service Quality (IRSQ) model. This architecture for quality operationalization represents a departure from classical measurement frameworks, facilitating a transition from the static paradigm of "quality assessment" toward a dynamic concept of "relational trust management". By integrating these methodologies, the model addresses the identified research gap, proposing a closed information loop in which behavioral customer experiences are directly translated into strategic management decisions. Consequently, the originality of this approach lies in its capacity to transform passive quality monitoring into an active system for reducing information asymmetry, thereby providing a robust framework for building competitive advantage in the property insurance sector.

2. Literature Review

Contemporary theory in insurance service management indicates the necessity of moving from static quality assessment models to dynamic systems that are adequate for the specific nature of "credence goods". The development of research on service quality in the insurance sector (Divisions I and II) gained momentum at the turn of the 20th and 21st centuries, becoming a key element of competitive strategies for insurance companies (Arasli et al., 2005; Zhou, 2004; Chi Cui et al., 2003; Othman, Owen, 2001). Currently, as indicated by Krasnikov et al. (2021) and Bhatia et al. (2023), digital transformation is radically modifying the

perception of quality – the determinant of success is no longer solely the timeliness of the service, but the assurance of a "seamless experience" and the speed of digital claims processing.

Fundamental to the analysis of this sector are the works of Joseph E. Stiglitz, who demonstrates that financial markets are not transparent, but are dominated by the phenomenon of information asymmetry (Stiglitz, 2013). In property insurance, this asymmetry leads to limited consumer rationality, which, combined with the institutional complexity of contracts, hinders their ability to assess the real quality of the protection purchased (Stiglitz, 2017). The information barrier constitutes the main source of uncertainty with which relational quality management must contend. In this view, the IRSQ model becomes an institutional mechanism serving to mitigate the effects of this asymmetry through the transparency of the claims handling process and the standardization of information flow. Furthermore, Akerlof (1970) argues that under conditions of asymmetry, low-quality services may drive out high-quality ones, necessitating systemic management of service standards. Additionally, according to Kahneman's (2011) theses on cognitive biases, clients often succumb to heuristics in risk assessment, which the IRSQ model corrects through the objectification of the claims handling process.

The theoretical foundation remains the SERVQUAL method (Table 1), which, despite critical remarks regarding its measurement reliability, serves as the starting point for most analyses in the financial sector (Ladhari et al., 2011; Njau et al., 2019; Gaur, Agrawal, 2006; Salemet et al., 2016). The adaptation of the SERVQUAL method to the realities of the insurance market, however, requires modifications that take into account the relational dimension of interaction (Lewis, Soureli, 2006).

A comprehensive literature review regarding the evolution and criticism of this model over three decades was provided by Mauri et al. (2013), who indicated the methodological limitations of the original approach while maintaining its status as the most frequently used instrument in marketing literature. In accordance with the concept established in the theory by Parasuraman et al. (1985), customer satisfaction is the result of comparing their perception of quality with initial expectations. In this context, the evolution of the author's research methodology – from the classic SERVQUAL method, through the proprietary Customer Service Quality Index (WJOK) – constituted a necessary step toward the construction of the Integrated Relational Service Quality (IRSQ) model.

While SERVQUAL allows for the assessment of gaps in technical dimensions, WJOK enables more precise quantification of satisfaction. In this context, the key theoretical dispute regarding the superiority of a performance-based approach over the expectations model was resolved by Cronin and Taylor (1994), whose argument for the SERVPERF model constitutes an important reference point for contemporary research on service quality in the financial sector (see also: Wells, Stafford, 1997; Przybytniowski, 2019, 2020, 2022, 2023).

In the Polish context, Kozioł-Nadolna et al. (2023) note that process innovation in property insurance is becoming an operational requirement. These authors, similar to Czerwiński (2021), emphasize that relational quality is evolving toward the personalization of offers based on data analysis. It is also worth referring to the works of Janssen et al. (2020), who point out that the subjective perception of quality is increasingly shaped by "social proof" (opinions in social media). Conversely, Chai et al. (2024) demonstrate that empathetic engagement plays a key role in long-term relationships, which directly corresponds to the assumptions of the IRSQ model regarding the reduction of a client's psychological tension.

The strategies of insurers have evolved from an aggressive approach toward a defensive one, based on customer retention. Researchers such as Lombardi (2005) and Ladhari et al. (2011) point out that the cost of acquiring a new client exceeds the cost of retaining an existing one, which makes service quality a determinant of profitability (Diacon, O'Brien, 2002; Moore, Santomero, 1999). In Poland, Kaczała (2018) points to a specific barrier: the client is often guided only by the amount of the premium, exhibiting low legal awareness regarding the general terms and conditions of insurance. Meanwhile, international literature (Wang et al., 2003; Shayestehfar, Yazdani, 2019; Alnaser et al., 2018) proves that customer loyalty is a moderator of the relationship between service quality and the insurer's economic results. Trust is built based on the conviction of the adequacy of the compensation and the transparency of procedures.

The key conclusion from the literature analysis is that the claims handling process constitutes the "moment of truth" (Zeithaml et al., 1988; Pointek, 1992). The shortage of integrated models prompted the development of the IRSQ model, in which quality is not a set of static indicators, but a dynamic cycle of feedback loops (PDCA). In this model, satisfaction is not the end of the process, but input data for subsequent interactions. This approach serves as a response to the postulate of Lewis and Soureli (2006), indicating the necessity of taking into account cultural differences in the perception of financial services, which is confirmed by studies by Farah (2017). Summarizing, the identification of the research gap – resulting from the lack of comprehensive studies on quality measurement in Polish property insurance using modern relational tools – justifies the need to apply the IRSQ model. It is a tool that translates subjective customer experiences into operational management priorities, enabling the mitigation of perceptual asymmetry and the construction of a lasting competitive advantage based on authentic institutional trust.

3. Methods

The study[1] was conducted on a sample of N = 658 respondents (Poland: N = 341, USA: N = 317) collected in 2023. A diagnostic survey method was employed using the computer-assisted web-based interviewing (CAWI) technique. The choice of the CAWI technique was dictated by its utility in reaching diverse age groups while maintaining high standards of objectivity and anonymity – factors critical for the reliability of measuring consumer attitudes (Frankfort-Nachmias et al., 2015; Houghton et al., 2017).

A non-random purposive sampling procedure was adopted, as the research objective necessitated the selection of individuals with specific experience in property insurance. This approach ensures that the sample structure is representative of key generational cohorts in both cultural contexts, as detailed in Table 1.

Table 1.
Structure of the research sample

Age group	Generation	Poland		USA	
		Sample size (n)	Share (%)	Sample size (n)	Share (%)
18-28	Generation Z	83	24.34	74	23.34
29-44	Millennials (Generation Y)	93	27.28	83	26.18
45-60	Generation X	87	25.51	81	25.56
60+	Baby Boomers	78	22.87	79	24.92
	Total	341	100.00	317	100.00

Source: Own elaboration based on empirical research (2023).

In contrast to traditional psychometric designs, the classic five-point Likert scale was replaced by an even, six-point ordinal forced-choice scale (Przybytniowski, 2019, 2022). This methodological choice was intended to mitigate central tendency bias – the tendency to select neutral options – which often obscures intergenerational differences (Garland, 1991). Scale values of 1-3 were interpreted as skepticism or lack of acceptance, while values of 4-6 indicated acceptance and trust.

This approach facilitates a clear polarization of opinions, enabling a precise verification of hypotheses regarding service quality gaps. The criteria for assessing financial services are presented in Table 2.

[1] The study was conducted in 2023 in strict accordance with the ethical principles of the Declaration of Helsinki. No sensitive personal data were collected, and the non-invasive nature of the procedure ensured compliance with academic regulations, exempting the project from formal bioethics committee approval. All participants were informed of the study's purpose; completing the questionnaire constituted informed consent.

Table 2.
Criteria for the process of assessing the quality of financial services offered

No.	Value	Assessment
1	1.00-1.82	Total dissatisfaction with the service offered (definitely not)
2	1.83-2.66	Insufficient satisfaction with the service offered (no)
3	2.67-3.51	Average satisfaction with the service offered (rather not)
4	3.52-4.36	Satisfactory (rather yes)
5	4.37-5.21	Satisfaction with the service offered (yes)
6	5.22-6.00	Full satisfaction with the service offered (definitely yes)

Note: The interval widths were calculated to ensure uniform distribution across the six-point scale, allowing for an equitable classification of consumer responses into distinct satisfaction levels within the IRSQ architecture.

Source: Own elaboration based on empirical research (2023).

The proposed scoring framework (Table 2) is a core component of the IRSQ model, developed to ensure high sensitivity in detecting gaps between perceived service delivery and behavioral expectations. The intervals were mathematically calibrated to provide granular diagnostic capabilities.

To assess how generational affiliation and market context (Poland vs. the US) differentiate the acceptance of financial services, statistical analyses were performed using pqStat (v. 1.8.0.476). Demographic characteristics were analyzed via descriptive statistics, while hypotheses were tested using nonparametric Pearson chi-square tests and Kruskal-Wallis H tests, chosen due to the ordinal nature of the scale and to ensure robustness against non-normality.

The internal consistency of the measurement scale was verified using Cronbach's alpha ($\alpha = 0.81$), which exceeds the commonly accepted threshold of 0.70, confirming the high reliability of the research tool (Nunnally, Bernstein, 1994). Although the non-random purposive nature of the sample indicates that the results are contextually specific, the adopted approach effectively captured universal generational patterns across cultural settings. The research tool was based on three key dimensions (Table 3).

Table 3.
Researched areas and exemplary elements for assessing the quality of property insurance services

Area	Elements of assessment
Reliability	timeliness of claim payouts, speed of service requests, effectiveness of claims settlement
Integrity	compliance of activities with contract terms, truthfulness of information
Assurance	employee competence, building trust
Empathy	individual treatment of the client
Infrastructure	accessibility of branches and communication channels

Source: Own elaboration based on empirical research (2023).

4. Research results. Verification of the proprietary service quality improvement model

Only complete questionnaires meeting the study criteria were qualified for the dependency analysis (Poland n = 341, USA n = 317).

4.1. General assessment of service quality

Initial assessments of property insurance services are presented in Table 4. Positive evaluations were recorded by 31.3% of respondents in Poland and 29.4% in the USA. The difference between the two markets amounts to 1.9 percentage points.

Table 4.
Average level of positive evaluations of property insurance services in 2023

Country	Average of positive evaluations (%)
Poland	31.3
USA	29.4

Source: Own elaboration based on conducted research.

4.2. Indicators of service quality (IRSQ model)

The quality of property insurance services was analyzed using the WJOK index across five dimensions: infrastructure, integrity, reliability, assurance, and empathy. The obtained index values (Sn) and weighted quality indicators (Sw) for both countries are presented in Tables 5 and 6.

Table 5.
Indicators of property insurance service quality in Poland in 2023 (N = 341)

Area	Sn	Sw
Infrastructure	-2.78	-0.25
Integrity	-14.05	-0.64
Reliability	-17.65	-0.62
Assurance	-11.02	-0.53
Empathy	-2.86	-0.24
General Average	**-11.174**	**-0.503**

Source: Own elaboration based on conducted research.

Table 6.
Indicators of property insurance service quality in the USA in 2023 (N = 317)

Area	Sn	Sw
Infrastructure	-2.58	-0.29
Integrity	-13.98	-0.64
Reliability	-17.09	-0.68
Assurance	-13.66	-0.57
Empathy	-3.68	-0.35
General Average	**-11.129**	**-0.510**

Source: Own elaboration based on conducted research.

In Poland, the lowest Sn index value was recorded for reliability (-17.65), followed by integrity (-14.05) and assurance (-11.02). Infrastructure and empathy reached -2.78 and -2.86, respectively. In the USA, the lowest Sn index values were also observed for reliability (-17.09), integrity (-13.98), and assurance (-13.66), while infrastructure and empathy reached -2.58 and -3.68, respectively. The aggregate Sn values for Poland (-11.174) and the USA (-11.129) indicate a comparable magnitude of service quality gaps in both markets.

4.3. Statistical dependencies between quality factors and consumer decisions

The relationship between insurance intermediary performance (professionalism, assistance in claims handling, and speed/timeliness of payouts) and the decision to conclude or re-conclude a contract was verified using Pearson's chi-square test. In all analyzed cases, the significance level (p) was lower than 0.05.

The results for the Polish market (Tables 7-9) demonstrate statistically significant links between the analyzed factors and client decisions. The specific results are as follows:

1. Intermediary professionalism: $\chi^2 = 42.565$, $p < 0.001$.
2. Assistance in claims handling: $\chi^2 = 7.804$, $p = 0.005$.
3. Speed/timeliness of payouts: $\chi^2 = 7.817$, $p = 0.005$.

Table 7.
Professionalism of the insurance intermediary as a factor determining the re-conclusion of a property insurance contract in Poland in 2023 (N = 341)

Statistical measure	Value
Pearson's Chi-square	42.565
df	1
p	0.000
Number of observations	341

Source: Own elaboration based on conducted research.

Table 8.
Relationship between the insurance intermediary and assistance in claims handling as a factor determining the conclusion of a property insurance contract in Poland in 2023 (N = 341)

Statistical measure	Value
Pearson's Chi-square	7.804
df	1
p	0.005
Number of observations	341

Source: Own elaboration based on conducted research.

Table 9.
Relationship between the insurance intermediary and the speed and timeliness of benefit or compensation payouts as a factor determining the conclusion of a property insurance contract in Poland in 2023 (N = 341)

Statistical measure	Value
Pearson's Chi-square	7.817
df	1
p	0.005
Number of observations	341

Source: Own elaboration based on conducted research.

A comparative analysis conducted for the United States market (Tables 10-12) reveals a nearly identical pattern of dependencies. The influence of intermediary professionalism on contract renewal remains the most prominent ($\chi^2 = 42.562$, $p < 0.001$), while the impact of assistance in claims handling and the timeliness of benefit payouts is also statistically significant. The specific results for the American market are as follows:

1. Intermediary professionalism: $\chi^2 = 42.562$, $p < 0.001$.
2. Assistance in claims handling: $\chi^2 = 7.803$, $p = 0.005$.
3. Speed/timeliness of payouts: $\chi^2 = 7.818$, $p = 0.005$.

These results confirm that these factors are critical determinants of customer decisions in the American insurance sector as well.

Table 10.
Professionalism of the insurance intermediary as a factor determining the re-conclusion of a property insurance contract in the USA in 2023 (N = 317)

Statistical measure	Value
Pearson's Chi-square	42.562
df	1
p	0.000
Number of observations	317

Source: Own elaboration based on conducted research.

Table 11.
Relationship between the insurance intermediary and assistance in claims handling as a factor determining the conclusion of a property insurance contract in the USA in 2023 (N = 317)

Statistical measure	Value
Pearson's Chi-square	7.803
df	1
p	0.005
Number of observations	317

Source: Own elaboration based on conducted research.

Table 12.
Relationship between the insurance intermediary and the speed and timeliness of benefit or compensation payouts as a factor determining the conclusion of a property insurance contract in the USA in 2023 (N = 317)

Statistical measure	Value
Pearson's Chi-square	7.818
df	1
p	0.005
Number of observations	317

Source: Own elaboration based on conducted research.

Statistical analysis (Tables 7-12) confirms the existence of significant dependencies between service quality assessments and clients' contractual decisions in both analyzed markets. The highest statistical dependence, indicated by the highest χ^2 values, was identified for the professionalism of insurance intermediaries in both examined markets, demonstrating the universal nature of these determinants in shaping clients' decisions regarding the continuation of cooperation with an insurer.

5. Discussion

The obtained research results and the proposed theoretical-methodological models fit into the broader evolution of the approach to quality management, in which classic perspectives based on measurable technical parameters are giving way to a systemic, relational, and behavioral perspective. In this context, particular importance is attached to moving away from treating quality as an additive category towards its interpretation as an emergent phenomenon, shaped in the process of dynamic interactions between the organization and the client. Such an approach remains consistent with the perspective of W. Edwards Deming (1986), who emphasized the importance of continuous improvement and feedback loops within the PDCA cycle, as well as with the concept of Joseph M. Juran (1988), who perceived quality in economic and process categories, pointing to the necessity of balancing the costs of quality with its impact on customer satisfaction and loyalty.

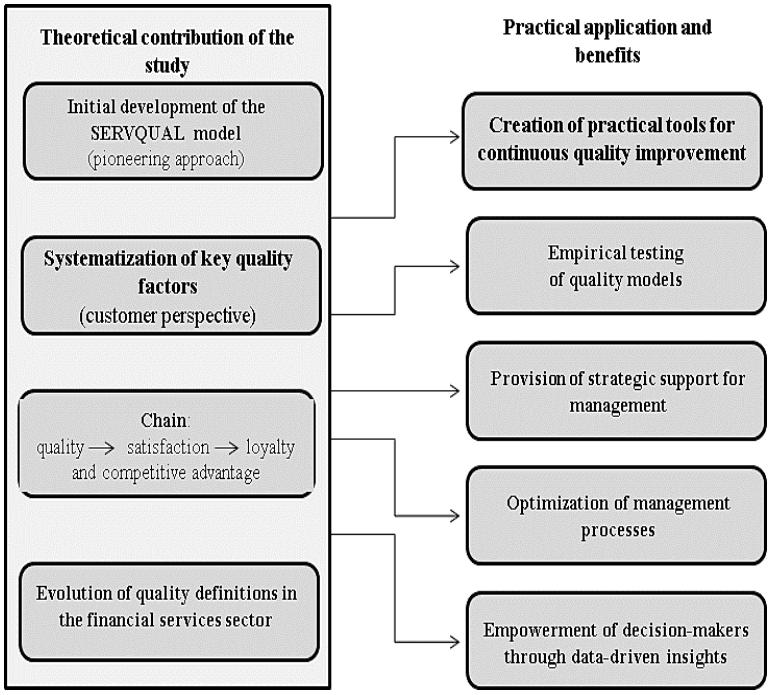

Figure 1. Conceptual evolution of the approach to quality management.
Source: Own elaboration.

Figure 1 serves as a starting point for the discussion, mapping the evolution of the theoretical foundations of quality and their direct translation into management practice. It illustrates the process of transitioning from classic SERVQUAL models towards integrated solutions that support management in decision-making based on precise data.

In light of the conducted research, the shift of focus from the formal conformity of a service with technical requirements towards a holistically understood customer experience proves particularly significant. In the insurance services sector, quality is not reducible to the provisions of general insurance conditions or procedural parameters, but encompasses the entirety of the interaction, including the method of communication, the level of empathy,

the transparency of information, and the organization's ability to reduce uncertainty and psychological tension during critical moments, such as the claims handling process. The results of empirical research unequivocally indicate the dominance of relational, personal, and competency factors over technical-material components in shaping customer satisfaction and loyalty.

Furthermore, this model illustrates (Figure 2) the mechanism of shaping quality as an emergent phenomenon that arises during the dynamic interaction between the client and the organization. It pays particular attention to the role of psychological mechanisms, such as anchoring or uncertainty reduction, which determine final customer satisfaction and loyalty.

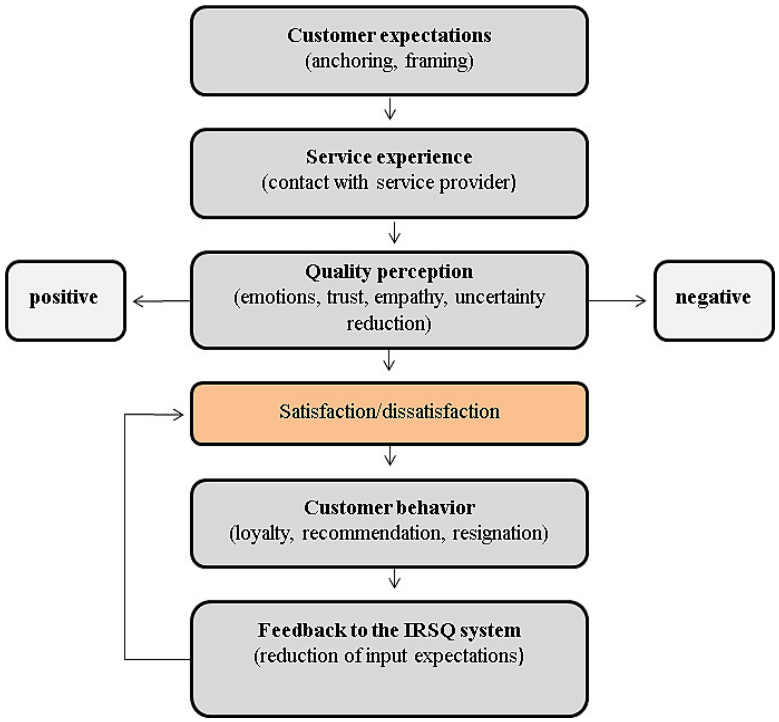

Figure 2. Service experience and assessment process (holistic relational approach).
Source: Own elaboration.

Against this background, the proposed Customer Service Quality Index (WJOK) takes on particular significance, constituting an attempt to operationalize the complex and multidimensional phenomenon of quality in a more objectified manner than in classic survey tools. The elimination of subjective weights assigned by respondents and the application of an algorithmic aggregation approach allow for reducing the arbitrariness of the measurement and increasing the comparability of results. At the same time, the implementation of a six-point rating scale eliminates the neutral category of response, which – consistent with research results – limits the phenomenon of apparent neutrality and strengthens the diagnostic nature of the obtained empirical data.

Classic SERVQUAL model (diagnosis)		Author's modification (WJOK) (measurement/gap identification)
Likert scale (odd, 5-point)	**Scale**	**Even 6-point scale** (forced respondent declaration)
Option to choose ("no opinion")	**Neutral responses**	**Rejection of neutral questionnaires** (elimination of distortions)
Subjective respondent weights (arbitrariness)	**Aggregation**	**WJOK weight algorithm** (aggregated and objectified)
General measurement of quality dimension	**Result**	**Precise identification of quality gaps and causes**

Figure 3. Operationalization of measurement: SERVQUAL vs. WJOK.

Source: Own elaboration.

To move on to methodological issues, Figure 3 juxtaposes classic measurement tools with the proposed Customer Service Quality Index (WJOK). It illustrates how the elimination of neutral responses and the replacement of subjective weights with an aggregation algorithm allow for a significant increase in diagnostic precision and the objectification of the study of quality gaps. However, WJOK does not function as an autonomous tool but constitutes an element of a broader research-management architecture, in which the modified SERVQUAL method serves as a starting point for diagnosis, WJOK as the operational layer for measuring quality gaps, and the concept of Integrated Relational Service Quality (IRSQ) as the interpretative-strategic level. Such a structure reflects a hierarchical-developmental model of quality information processing, in which empirical data are subject to gradual aggregation up to the level of management decisions.

The next stage is the visualization of the synergy of these tools within the framework of an extended Deming cycle, where quality becomes the result of continuous, systemic organizational learning. The synthesis of the proposed solutions, covering conceptual evolution, operationalization of measurement, and integration of the model within the improvement cycle, is presented in Figure 4. This figure demonstrates how SERVQUAL, WJOK, and IRSQ cooperate within the planning, measurement, analysis, and strategic action phases, creating a closed system of feedback loops.

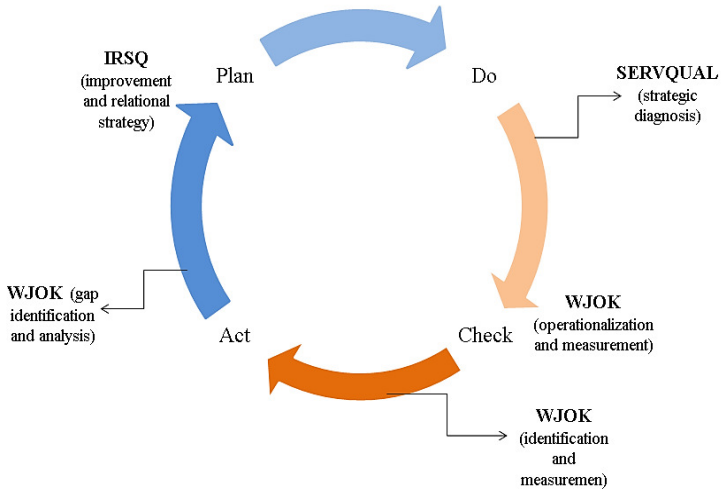

Figure 4. Integrated quality improvement cycle in the PDCA model.

Source: Own elaboration.

Complementing the hierarchical-developmental perspective and the operationalization of the PDCA loop is a dynamic model presenting the relationships between the SERVQUAL structure, the WJOK index, and the IRSQ concept. This construction constitutes an expansion of classic quality management concepts, in particular the process approach and the improvement cycle formulated by W. Edwards Deming (1986), in which quality is the result of continuous organizational learning under conditions of feedback from the environment. At the same time, the model remains consistent with Juran's approach, especially in the scope of the triad: quality planning, quality control, and quality improvement, transferred to the level of an integrated relational system.

In the operational perspective, the SERVQUAL model acts as a diagnostic tool (Plan), WJOK is responsible for measurement and identification of quality gaps (Do and Check), while IRSQ determines the interpretative framework and strategic corrective actions (Act). In this way, the classic PDCA cycle is extended by a relational and behavioral dimension, taking into account the specificity of public trust services.

The results of empirical research confirm that quality assessment in the insurance sector is holistic and non-decomposable – clients do not separate technical components from relational ones but perform a synthetic assessment of the entire service experience. In this sense, quality takes the form of an emergent phenomenon, in accordance with the assumptions of the IRSQ model, in which the integration of three dimensions plays a key role: technical, functional, and relational quality.

A particularly significant result of the research remains the identification of cognitive dissonance between the level of costs incurred (insurance premium) and the subjectively felt level of financial security. This phenomenon indicates that customer satisfaction is shaped not only by service parameters but also by psychological and economic-behavioral mechanisms, such as the anchoring effect, framing, or loss aversion. Thus, the process of quality assessment goes beyond rational economic calculation and also includes an emotional and cognitive component.

In the behavioral phase of the model, a significant relationship was confirmed between satisfaction and loyalty behaviors, including both the propensity to recommend and decisions regarding the continuation of cooperation. At the same time, a key element of the structure remains the feedback loop, within which client behaviors redefine future expectations, leading to a dynamic reconstruction of the entire quality assessment system. This mechanism constitutes an empirical reflection of the PDCA logic and the concept of continuous quality improvement according to Deming (1986).

The research results also indicate that under conditions of increasing complexity of financial products, the organization's ability to reduce information asymmetry and build trust through transparent communication becomes a primary source of competitive advantage. This implies the necessity of simplifying the message, eliminating hermetic industry jargon, and consistently managing the customer experience throughout the entire service life cycle.

The summary of the discussion is the presentation of the IRSQ model (Figure 5), which integrates the theoretical dimension with the practical one in order to build a lasting competitive advantage. This figure emphasizes that the key to success in the modern services sector is transparent communication and the reduction of cognitive dissonance, which directly translates into customer trust and the stability of business relationships. In this perspective, the proposed SERVQUAL – WJOK – IRSQ model constitutes a coherent, multi-level analytical-decision structure, in which quality measurement, its operationalization, and strategic interpretation form a closed feedback loop system. SERVQUAL serves as the starting point for diagnosis, WJOK constitutes a tool for the quantification and aggregation of quality gaps, while IRSQ integrates the obtained results into a framework of systemic management of relational service quality.

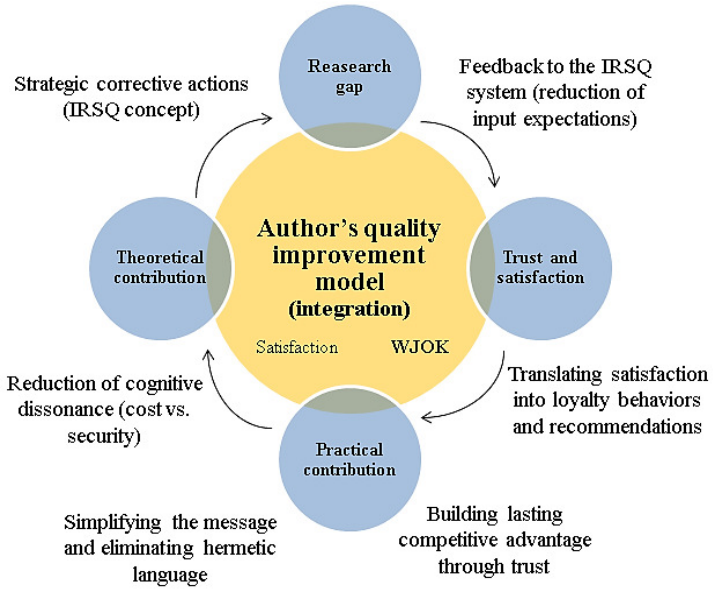

Figure 5. Systemic view of the IRSQ model as a tool for competitive advantage.
Source: Own elaboration.

Furthermore, the systemic nature of the proposed IRSQ model, validated here in the property insurance sector, is currently being adapted to the banking and life insurance segments, suggesting its potential as a universal framework for customer experience management in public trust services.

From a management practice perspective, the key challenge for the full operationalization of the IRSQ model remains its integration with CRM-class information systems and Claims Management Systems. In order to transform IRSQ into a dynamic real-time feedback tool, organizations should strive to automate the process of collecting behavioral data at every stage of the customer journey – from the claim notification to the final settlement. The implementation of analytical algorithms that correlate operational metrics (such as the claims processing time) with declarative satisfaction ratings in real time would enable managers to make immediate corrective decisions. Such a data-driven architectural approach would allow not only for continuous monitoring of quality gaps but also for predictive trust management, eliminating information asymmetry at the moment of its emergence, rather than only after the service cycle is completed. Consequently, the presented approach not only organizes the relationships between measurement and quality management but also extends the classic models of Deming (1986) and Juran (1998) with a behavioral and relational dimension characteristic of modern public trust services (cf. Opolski, Modzelewski, 2024; Grönroos, 2011; Parasuraman, Zeithaml, Berry, 1985). This enables a fuller understanding of the mechanisms of shaping customer satisfaction and their practical use in building a lasting competitive advantage of the organization.

6. Conclusions and recommendations

The empirical research and theoretical analysis conducted allow for the formulation of conclusions of both a cognitive and an applicative nature. The main result of the work undertaken is the development and validation of the Integrated Relational Service Quality (IRSQ) model, which constitutes a significant extension of classical quality management paradigms. The following key conclusions have been formulated based on the synthesis of research findings:

1. Reorientation of the quality paradigm (theoretical dimension) – it was demonstrated that in the sector of credence goods, the classic approach to quality, based on Juran's trilogy and the Deming concept, has exhausted its diagnostic potential when confronted with customer perceptual asymmetry. The research proved that satisfaction in insurance is not a derivative of conformity with a technical standard, but an effect of reducing psychological tension caused by service uncertainty. Thus, the proprietary IRSQ concept fills a gap in the subject literature, shifting the weight of analysis from "quality as a process result" to "quality as a relationship management process".

2. Operationalization of subjectivism (methodological dimension) – the application of the proprietary WJOK index in combination with a forced-choice scale allowed for the elimination of the central tendency error, which constitutes a significant methodological correction to the commonly used SERVQUAL model. The results confirm that the quantification of relational quality is possible only through the application of tools that, in the measurement process, force the client to hierarchize experiences, rather than merely evaluate them on a point scale. It was also confirmed that the visualization of the model is an indispensable element of scientific discourse, serving as a process map for implementing IRSQ assumptions in corporate structures.
3. Strategic and applicative implications (synthesis of findings) – the empirical research validates the hypothesis that service quality in the property insurance sector is a multidimensional construct where relational and competency-based factors are primary drivers of client decisions. Key conclusions include:
   a) universal nature of quality gaps – despite different institutional environments, both the Polish and American insurance markets exhibit significant service quality gaps. The negative values of the Sn and Sw indices confirm that current service delivery fails to meet client expectations across all analyzed areas (infrastructure, integrity, reliability, assurance, and empathy);
   b) dominance of the "Intermediary Effect" – the high statistical significance of the relationship between intermediary professionalism and contract renewal decisions underscores that the insurance intermediary is not merely a sales agent, but a crucial gatekeeper of service quality. Client satisfaction is inextricably linked to the personal support and guidance provided during the claims handling process;
   c) shift from technical to relational paradigms – the results suggest that efficiency in claims processing (speed and timeliness) is a necessary, but insufficient, condition for building long-term loyalty. Clients prioritize "relational quality" – trust-building communication and empathetic support – over purely procedural accuracy;
   d) strategic necessity for insurance organizations – to mitigate the identified quality gaps, insurers must transition from a reactive, process-oriented approach to a proactive, integrated relational strategy. Improving the professionalism of intermediaries and enhancing the transparency of information are the most potent instruments for reducing the perceived gap between expected and received service quality. The IRSQ model, therefore, constitutes a ready-to-use diagnostic tool that allows management to systematically level gaps in areas most critical to customer loyalty, integrating PDCA phases with direct behavioral feedback;
4. Comparative dimension (Poland vs. USA) – the empirical analysis revealed a surprising convergence of results across both studied markets, which challenges the thesis of strong cultural determination in the perception of insurance service quality. Despite systemic differences, the Sn and Sw scores for Poland (mean -11.174; -0.503)

and the USA (mean -11.129; -0.510) indicate an almost identical level of quality gap. This confirms the universal nature of the "intermediary effect" and the deficits in information transparency common to both markets. These findings suggest that the contemporary client in the *credence goods* sector exhibits a unified pattern of behavior, in which expectations regarding relational quality are independent of the degree of a market's institutional development. Consequently, quality improvement strategies based on the IRSQ model are transboundary in nature and can serve as a foundation for standardizing customer experience management on an international scale.

5. Research limitations and future directions – the conducted study, despite its cognitive and applicative value, is not free of limitations. First, the study focused on property insurance, which may restrict the immediate generalization of the IRSQ model to other segments, such as life or health insurance. Second, the reliance on self-reported consumer data, while mitigated by the forced-choice scale, carries a risk of subjective perception bias. Third, the cross-sectional nature of the study provides a static snapshot of the quality gap, which may not fully capture the dynamic impact of sudden market or regulatory shifts.

   However, the universal nature of the IRSQ model necessitates further validation. While the model is currently being adapted for the banking sector and life insurance, future research will focus on longitudinal applications across these diverse financial service segments to confirm the stability of the WJOK index and its predictive power regarding long-term customer loyalty. Furthermore, as the model is increasingly tested in digital-first financial environments, upcoming studies will investigate how the "intermediary effect" evolves when human interaction is augmented or replaced by automated advisory systems.

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STRATEGIC ADAPTATION IN HOSPITALITY: DYNAMIC CAPABILITIES AND CUSTOMER EXPERIENCE MANAGEMENT IN A TURBULENT ENVIRONMENT

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Purpose: The purpose of this conceptual paper is to explore the integration of dynamic capabilities and customer experience management within the context of hospitality, particularly fine dining, under turbulent environmental conditions. The study synthesizes theoretical approaches combining dynamic managerial, marketing, and innovation capabilities with the principles of the experience economy.
Design/methodology/approach: The paper is based on a systematic and integrative literature review and builds on empirical insights from previous research (Przymus, 2024). It examines how dynamic capabilities enable proactive adaptation, resource reconfiguration, and customer-centered innovation in hospitality organizations.
Findings: The analysis highlights that dynamic managerial, marketing, and innovation capabilities collectively enhance the customer experience through strategic sensing, seizing, and transforming processes. These capabilities allow fine dining restaurants to sustain competitiveness by co-creating value and ensuring resilience during crises.
Research limitations/implications: As a review paper, this study is limited to secondary sources, but it provides a framework for future empirical testing in diverse service contexts.
Practical implications: The findings suggest that hospitality managers should cultivate dynamic capabilities that foster continuous learning, agile marketing, and experiential innovation to strengthen customer loyalty and strategic resilience.
Originality/value: The paper advances understanding of how dynamic capabilities intersect with the experience economy in turbulent hospitality environments, offering an integrative model for strategic adaptation.
Keywords: dynamic capabilities, hospitality, customer experience, experience economy, turbulent environment.
Category of the paper: Conceptual paper.

1. Introduction

The hospitality industry is undergoing a profound transformation, shaped by global turbulence, technological acceleration, and shifting social expectations. Over the past decade, crises such as the COVID-19 pandemic, energy shortages, and inflationary pressures have disrupted tourism and food-service sectors worldwide, forcing organizations to rethink their operating models and sources of value creation. In this volatile environment, the ability to learn, adapt, and renew strategic resources has emerged as the primary determinant of survival and competitiveness. These challenges are particularly visible in the fine-dining segment, where businesses depend on sensory, emotional, and cultural value rather than price efficiency (Przymus, 2024). Fine-dining restaurants exemplify the tension between vulnerability and innovation: while they rely heavily on discretionary spending and social prestige, they also serve as laboratories of creative experimentation and experience design (Mossberg, 2008; Pine, Gilmore, 1999).

Recent research highlights that crises function as both threats and catalysts for innovation in hospitality (Burton, Dickinger, 2025). In times of disruption, leadership and dynamic capabilities become critical micro-foundations of resilience. Burton and Dickinger (2025) show that transformational and participatory leadership styles foster sensing, seizing, and reconfiguring routines that enable innovation even under extreme uncertainty. These findings confirm that innovation is not a by-product of crisis recovery but an integral outcome of firms' capability to learn and transform strategically.

Building on the resource-based view (RBV, Barney, 1991), the dynamic-capabilities framework (Teece, Pisano, Shuen, 1997; Eisenhardt, Martin, 2000) explains how organizations renew their competencies to address environmental turbulence. Dynamic capabilities, understood as the firm's ability to integrate, build, and reconfigure resources, translate into agility, flexibility, and resilience. In hospitality, they materialize through the interplay of three domains: managerial capabilities (cognitive and leadership skills that enable vision and coordination), marketing capabilities (market sensing, customer-experience management, and brand storytelling), and innovation capabilities (service design, technological adoption, and creative experimentation) (Przymus, 2024). Together, these capabilities allow firms to navigate uncertainty by aligning operational excellence with experiential differentiation.

Empirical research further demonstrates how organizational resources enable these adaptive capacities. Chasapi et al. (2024) find that financial and technological capital directly strengthen agility-related dynamic capabilities, specifically market-capitalizing and operational-adjustment agility, while social capital exerts mixed effects. Their study underscores that during crises the quality and composition of resources determine whether firms can develop the dynamic agility needed to survive. Similarly, Ahachmi et al. (2025) analyze gastronomic firms in Morocco and conclude that dynamic capabilities provide the conceptual foundation for

organizational resilience. Sensing opportunities, seizing resources, and reconfiguring competencies from the triad through which restaurants transform exogenous shocks into renewal pathways.

In addition to environmental and structural turbulence, the hospitality sector faces the unprecedented acceleration of digital transformation. Artificial intelligence (AI), machine learning, and big-data analytics have redefined customer interaction and service design. Alam et al. (2025) show that technology readiness and AI adoption enhance value creation, though their effects are moderated by technological turbulence. Dynamic capabilities mediate these processes, initially creating transitional complexity but ultimately enabling sustainable competitive advantage. Digitalization, therefore, not only modernizes operational systems but also extends the scope of experiential value through personalization, predictive service, and operational efficiency. Nevertheless, it raises ethical and managerial questions regarding authenticity, privacy, and the human dimension of service encounters (Kandampully, Zhang, Bilgihan, 2015).

Parallel to technological transformation, sustainability and ethical consumption have become defining imperatives of post-pandemic hospitality. Customers increasingly demand experiences that are environmentally responsible, socially conscious, and culturally authentic (Buhalis, Sinarta, 2019). Fine-dining establishments must reconfigure sourcing, production, and storytelling to align luxury with responsibility. Sustainability-oriented dynamic capabilities, stakeholder integration, continuous learning, and innovation in supply networks, become essential for balancing profitability with legitimacy (Teece, 2018). Recent evidence from Warwick (2025) illustrates how trust-based supplier relationships, local sourcing, and collaborative innovation act as dynamic relational capabilities that underpin resilience and authenticity in the Italian restaurant sector.

From a creative perspective, technology and artistry intersect in the making of culinary experiences. Ramirez (2025), adopting an Actor-Network Theory approach, portrays chefs, machines, and ingredients as co-actors in the co-creation of meaning and sensory innovation. His findings reveal that the technological mediation of creativity, the "machines as artisans" phenomenon, reshapes professional identities in fine dining, expanding the boundaries of the experience economy into the digital realm. This insight aligns with the broader view that the experience economy (Pine, Gilmore, 1999) transforms production into "staged experiences", where customers become co-participants in emotionally charged, narrative-driven encounters (Hemmington, 2007; Richards, 2021). Fine dining, with its choreographed service and symbolic storytelling, epitomizes this experiential turn.

Taken together, these contemporary studies demonstrate that the hospitality industry's resilience and competitiveness depend on its ability to orchestrate dynamic capabilities across multiple layers, technological, organizational, and relational, within the experience-driven context of service delivery. Leadership acts as the catalyst linking managerial cognition with innovation and customer experience, while AI, sustainability, and cultural authenticity redefine

the boundaries of strategic adaptation. In this evolving landscape, turbulence becomes not merely an external threat but a creative force that compels organizations to evolve toward agility, empathy, and experiential excellence.

This review paper therefore aims to synthesize current theoretical and empirical insights to explain how dynamic capabilities and the experience-economy logic jointly underpin strategic adaptation in hospitality, particularly in fine dining. Drawing on Przymus (2024), it proposes an integrative conceptual model illustrating how managerial, marketing, and innovation capabilities interact with customer-experience management in turbulent environments. The next section outlines the theoretical foundations of dynamic capabilities, followed by an exploration of the experience economy and its strategic implications. The paper concludes by integrating these perspectives into a holistic framework and identifying future research directions for advancing hospitality management in the era of digital and experiential transformation.

1.1. Methodological Approach

This paper adopts an integrative literature review approach to synthesize research on dynamic capabilities, customer experience management, and the experience economy in hospitality. Integrative reviews are particularly suitable for examining interdisciplinary phenomena because they combine conceptual, theoretical, and empirical contributions originating from different research traditions (Torraco, 2005; Snyder, 2019).

The literature search focused on the key themes underlying the study, including dynamic capabilities, customer experience management, experience economy, hospitality, fine dining, organizational resilience, service innovation, digital transformation, and AI in hospitality. Searches were conducted using major academic databases, including Scopus, Web of Science, ScienceDirect, Emerald Insight, and Google Scholar.

Priority was given to peer-reviewed publications published between 2015 and 2025 in order to capture recent developments related to technological transformation, sustainability, organizational resilience, and post-pandemic adaptation. At the same time, seminal contributions forming the theoretical foundations of the study, such as Teece et al. (1997), Eisenhardt and Martin (2000), Pine and Gilmore (1999), and Teece (2007), were retained due to their enduring conceptual relevance.

The review included studies addressing dynamic capabilities, customer experience, innovation, resilience, organizational learning, and strategic adaptation in hospitality and related service industries. Following an initial screening of abstracts and conclusions, publications demonstrating the strongest theoretical or empirical relevance were selected for detailed analysis and synthesis. Particular attention was devoted to recent studies examining leadership, digital transformation, artificial intelligence, sustainability, and experiential value creation in hospitality environments.

Rather than aiming for exhaustive bibliometric coverage, the review seeks to develop an integrative conceptual understanding of how dynamic managerial, marketing, and innovation capabilities support customer experience management under conditions of environmental turbulence. The resulting framework reflects a theory-building orientation informed by both contemporary literature and previous empirical research conducted by the author (Przymus, 2024).

2. Theoretical foundations. Dynamic Capabilities in Turbulent Environments

The theory of dynamic capabilities (DC) provides a powerful framework for understanding how organizations survive and thrive in environments characterized by volatility and discontinuity. First introduced by Teece, Pisano, and Shuen (1997), the concept was designed to extend the resource-based view (RBV) by explaining how firms renew, integrate, and reconfigure their resource base in response to environmental change. While the RBV emphasizes the possession of valuable, rare, and inimitable resources (Barney, 1991), dynamic capabilities focus on processes of renewal, how organizations learn, adapt, and transform their resources to maintain competitiveness (Eisenhardt, Martin, 2000). In essence, DCs represent the firm's ability to sense opportunities and threats, seize resources and competencies, and transform internal structures to sustain long-term advantage (Teece, 2007).

2.1. Evolution of the Dynamic Capabilities Perspective

Over the past two decades, the dynamic-capabilities framework has evolved from an abstract strategic concept to a measurable, context-specific theory of organizational adaptation. Early scholarship focused on high-technology and manufacturing sectors; however, contemporary studies demonstrate its applicability to services and hospitality, where value is co-created through human interaction, emotion, and experience (Kandampully, Zhang, Bilgihan, 2015). In this context, dynamic capabilities operate not only through technological or process adaptation but also through managerial cognition, learning routines, and leadership behaviors (Helfat, Martin, 2015).

Recent contributions emphasize that dynamic capabilities are multi-level and micro-founded, shaped by individual and organizational factors. Burton and Dickinger (2025) highlight leadership as a critical antecedent of dynamic capabilities in hospitality. Transformational leaders, characterized by vision and emotional intelligence, encourage experimentation, empower employees, and sustain learning environments that foster innovation under crisis. Transactional or authoritarian leadership, in contrast, tends to inhibit sensing and seizing processes. These findings align with the microfoundations perspective, which views

individual knowledge, managerial cognition, and social interaction as the building blocks of organizational adaptation (Felin et al., 2012).

2.2. Dynamic Capabilities as Enablers of Organizational Agility

Hospitality organizations operate within environments marked by technological turbulence, fluctuating demand, and high emotional labor. Chasapi et al. (2024) empirically validate that the development of dynamic capabilities, particularly agility, depends on the effective mobilization of financial, technological, and social capital. Their research shows that technological and financial resources strengthen market-capitalizing agility and operational-adjustment agility, while social capital may have an ambiguous role, enhancing cohesion but occasionally constraining change. This evidence confirms that dynamic capabilities do not emerge automatically from resources but are strategically enacted through learning and managerial orchestration.

In fine dining, agility translates into the ability to anticipate culinary trends, design new experiential formats, and reconfigure supplier and customer relationships quickly. As Ahachmi et al. (2025) note, dynamic capabilities in gastronomy foster organizational resilience, the ability to absorb shocks, maintain core values, and reimagine operations without losing authenticity. Their theoretical model demonstrates that sensing, seizing, and reconfiguring processes underpin resilience by balancing efficiency and creativity. In this sense, resilience can be understood as a manifestation of dynamic capabilities, rather than a separate construct.

2.3. Leadership, Organizational Learning, and Emotional Labor in Hospitality Adaptation

Recent hospitality research increasingly emphasizes that dynamic capabilities are not solely organizational routines but are deeply embedded in human agency, leadership behaviors, managerial cognition, and social interaction (Teece, 2007; Felin et al., 2012; Helfat, Martin, 2015). Recent studies in hospitality further demonstrate that leadership and organizational learning play a critical role in enabling firms to sense, seize, and transform opportunities under turbulent conditions (Burton, Dickinger, 2025). In service-intensive industries such as hospitality, where value is co-created through interpersonal encounters and emotional engagement, these human-centered factors constitute important microfoundations of strategic adaptation (Hemmington, 2007; Lemon, Verhoef, 2016).

Among the various leadership approaches discussed in the literature, transformational leadership appears particularly relevant in turbulent environments. By promoting vision, empowerment, and experimentation, transformational leaders foster organizational learning, innovation, and adaptive resilience (Burton, Dickinger, 2025). Participative leadership further strengthens adaptation by encouraging knowledge sharing, employee involvement, and collaborative problem-solving (Helfat, Martin, 2015; Burton, Dickinger, 2025), while transactional leadership contributes primarily to operational stability, service consistency,

and process control (Bass, 1985; Burton, Dickinger, 2025). The hospitality literature suggests that organizations benefit from balancing these complementary leadership approaches rather than relying exclusively on any single style (Burton, Dickinger, 2025).

The importance of leadership is particularly visible in hospitality organizations, where service quality depends heavily on employee engagement, emotional performance, and customer interaction (Hemmington, 2007; Pine, Gilmore, 1999). Emotional labor, defined as the regulation and expression of emotions during service encounters, represents a critical component of customer experience creation (Hochschild, 1983; Hemmington, 2007). Employees are expected not only to perform technical tasks but also to communicate attentiveness, warmth, and authenticity, all of which influence customer perceptions and experiential value (Lemon, Verhoef, 2016; Przymus, 2024). Consequently, leadership styles affect not only organizational adaptability but also the emotional climate that shapes service outcomes and customer satisfaction (Burton, Dickinger, 2025).

Organizational learning further reinforces dynamic capabilities by enabling firms to continuously acquire, interpret, and apply knowledge derived from customer interactions, market signals, and operational experience (Zollo, Winter, 2002; Teece, 2007). In hospitality settings, learning is often driven by experimentation, feedback integration, and continuous refinement of service concepts (Burton, Dickinger, 2025; Przymus, 2024). Fine-dining restaurants provide a particularly illustrative example, as chefs and service teams constantly reinterpret customer feedback, culinary trends, and changing expectations in order to refine menus, narratives, and service practices (Przymus, 2024). Through these processes, organizations transform tacit and experiential knowledge into organizational capabilities that support long-term adaptation and innovation (Zollo, Winter, 2002; Helfat, Martin, 2015).

Taken together, leadership, organizational learning, and emotional labor transform dynamic capabilities from abstract strategic constructs into everyday organizational practices. By shaping how hospitality organizations generate knowledge, coordinate employees, and deliver emotionally engaging experiences, these microfoundations strengthen both organizational adaptability and experiential value creation in turbulent environments (Teece, 2007; Burton, Dickinger, 2025; Przymus, 2024).

2.4. AI, Digital Transformation, and Experiential Personalization in Hospitality

The accelerating pace of digital transformation has significantly expanded the strategic relevance of dynamic capabilities in hospitality. Technologies such as artificial intelligence (AI), machine learning, predictive analytics, and customer-data platforms are reshaping how organizations sense customer expectations, personalize experiences, and manage operational complexity (Warner, Wäger, 2019; Alam et al., 2025). In turbulent environments, digitalization functions not only as a technological shift but also as a catalyst for organizational agility, learning, and innovation (Teece, 2007; Warner, Wäger, 2019).

Recent studies suggest that AI enhances hospitality firms' ability to create value through advanced sensing and personalization mechanisms. Alam et al. (2025) demonstrate that technology readiness and AI adoption improve responsiveness, service quality, and adaptive decision-making, although these effects are moderated by technological turbulence. Similarly, Chasapi et al. (2024) argue that technological resources and digital capabilities strengthen organizational agility and support more effective responses to environmental uncertainty. Dynamic capabilities therefore play a critical role in translating technological investments into sustainable experiential advantages (Teece, 2007; Alam et al., 2025).

In practice, AI-driven solutions increasingly support both operational efficiency and customer experience management. Predictive analytics enables hospitality organizations to forecast demand fluctuations, optimize staffing and inventory decisions, and anticipate customer preferences (Alam et al., 2025). AI-supported reservation systems can improve service flow and capacity management, while CRM-based recommendation engines facilitate personalized dining experiences and customer engagement (Lemon, Verhoef, 2016; Alam et al., 2025). In fine dining, AI applications may support individualized tasting-menu recommendations, wine-pairing suggestions, and sentiment analysis based on customer feedback and online reviews, thereby strengthening organizational sensing capabilities through the transformation of customer data into actionable experiential insights (Przymus, 2024).

Digital technologies also contribute to experiential storytelling and customer engagement. Social-media analytics, immersive interfaces, and personalized digital communication allow hospitality firms to create experiences that are increasingly aligned with customer identities, preferences, and expectations (Pine, Gilmore, 1999; Lemon, Verhoef, 2016). From the perspective of the experience economy, digital technologies can therefore enhance experiential value by supporting personalization and customer participation in the co-creation of experiences (Pine, Gilmore, 1999).

However, the growing role of technology also creates a tension between efficiency and authenticity. While AI improves personalization and responsiveness, excessive technological mediation may weaken the human warmth, emotional connection, and authenticity that remain central to hospitality experiences (Hemmington, 2007; Pine, Gilmore, 1999; Przymus, 2024). This challenge is particularly visible in fine dining, where customers often seek memorable interpersonal interactions alongside culinary excellence.

Ramirez (2025), drawing on Actor-Network Theory, argues that technology should be viewed not merely as an operational tool but as a co-actor in culinary creativity and experiential value creation. In this perspective, chefs, ingredients, machines, and digital systems collectively participate in the production of sensory experiences, extending the possibilities for innovation and experiential differentiation. Such findings suggest that digital transformation can support rather than replace the human dimensions of hospitality when technology is integrated into broader experiential design processes.

Ultimately, the strategic value of AI depends on an organization's ability to balance technological intelligence with human-centered service design. Digital transformation should therefore be understood as an enabler of experiential adaptation rather than an end in itself (Warner, Wäger, 2019; Alam et al., 2025). By integrating technological innovation with customer experience management, hospitality organizations can strengthen their capacity to sense, seize, and transform opportunities in increasingly turbulent environments (Teece, 2007; Przymus, 2024).

2.5. Dynamic Managerial, Marketing, and Innovation Capabilities in Hospitality

While the dynamic capabilities framework provides a broad explanation of how organizations adapt to changing environments (Teece et al., 1997; Eisenhardt, Martin, 2000; Teece, 2007), hospitality scholars have increasingly emphasized the importance of specific capability domains that support strategic renewal and experiential value creation (Przymus, 2024). In particular, dynamic managerial capabilities, dynamic marketing capabilities, and dynamic innovation capabilities have emerged as complementary mechanisms through which hospitality organizations sense opportunities, respond to customer needs, and develop sustainable competitive advantages (Adner, Helfat, 2003; Helfat, Martin, 2015; Barrales-Molina et al., 2014).

Dynamic managerial capabilities (DMCs) refer to managers' abilities to build, integrate, and reconfigure organizational resources in response to environmental change (Adner, Helfat, 2003; Helfat, Martin, 2015). These capabilities are rooted in managerial cognition, human capital, and social capital, which collectively influence how leaders interpret environmental signals, evaluate strategic opportunities, and orchestrate organizational transformation (Harris, Helfat, 2016; Helfat, Martin, 2015). In hospitality environments characterized by uncertainty and rapidly evolving customer expectations, managerial capabilities play a critical role in balancing operational efficiency with strategic adaptability (Burton, Dickinger, 2025). Effective leaders contribute not only to organizational performance but also to the development of learning-oriented cultures that foster innovation, resilience, and customer-centricity (Zollo, Winter, 2002; Burton, Dickinger, 2025).

Dynamic marketing capabilities (DMktCs) extend this perspective by focusing on an organization's ability to acquire, interpret, and utilize market knowledge in order to create superior customer value (Bruni, Verona, 2009; Fang, Zou, 2009; Barrales-Molina et al., 2014). These capabilities encompass market sensing, customer relationship management, service adaptation, and the continuous evaluation of changing customer expectations (Mitręga, 2016; Mitręga, 2018). In hospitality, where value is co-created through interactions between customers and service providers, dynamic marketing capabilities enable organizations to personalize experiences, strengthen customer engagement, and respond proactively to market turbulence (Lemon, Verhoef, 2016; Pine, Gilmore, 1999). Consequently, they represent

an important link between strategic adaptation and customer experience management (Przymus, 2024).

Dynamic innovation capabilities (DICs) complement managerial and marketing capabilities by facilitating the development and implementation of new products, services, processes, and experiential concepts (Cheng, Chen, 2013; Strønen et al., 2017). In hospitality organizations, innovation extends beyond technological improvements and often includes service design, sustainability initiatives, experiential staging, and novel forms of customer engagement (Pine, Gilmore, 1999; Ramirez, 2025). Through innovation capabilities, firms are able to transform market insights, customer feedback, and organizational learning into differentiated value propositions that enhance customer experiences and strengthen competitive positioning (Strønen et al., 2017; Przymus, 2024).

Although these capability domains differ in focus, they are highly interdependent. Dynamic managerial capabilities provide strategic direction and resource orchestration (Adner, Helfat, 2003; Helfat, Martin, 2015), dynamic marketing capabilities facilitate customer and market sensing (Bruni, Verona, 2009; Mitręga, 2016), while dynamic innovation capabilities enable the creation and implementation of new experiential solutions (Cheng, Chen, 2013; Strønen et al., 2017). Together, they form an integrated capability system that supports organizational agility, resilience, and customer experience management in turbulent hospitality environments (Przymus, 2024; Ahachmi et al., 2025).

From the perspective of the experience economy, the integration of managerial, marketing, and innovation capabilities is particularly significant because memorable experiences require not only operational excellence but also continuous adaptation, customer insight, and creative value creation (Pine, Gilmore, 1999; Lemon, Verhoef, 2016). As a result, these three capability domains provide an important theoretical foundation for understanding how hospitality organizations create, sustain, and renew experiential value under conditions of environmental turbulence (Przymus, 2024).

2.6. Integrating Dynamic Capabilities and Organizational Learning

The literature reviewed so far indicates that dynamic capabilities in the hospitality industry result from the interaction between organizational resources, leadership practices, learning processes, and technological adaptation (i.e., Chasapi et al., 2024; Burton, Dickinger, 2025; Alam et al., 2025). Rather than functioning as isolated mechanisms, sensing, seizing, and transforming capabilities are embedded within broader organizational systems that continuously generate, interpret, and apply knowledge (Teece, 2007; Helfat, Martin, 2015). This perspective aligns with the view that dynamic capabilities develop through iterative learning cycles rather than linear processes (Zollo, Winter, 2002; Eisenhardt, Martin, 2000; Ahachmi et al., 2025).

In hospitality organizations, learning is particularly important because customer expectations, service technologies, and competitive conditions evolve rapidly, requiring continuous adaptation and innovation (Pine, Gilmore, 1999; Lemon, Verhoef, 2016; Burton, Dickinger, 2025). Knowledge is acquired through customer interactions, employee experiences, market observation, and experimentation with new service concepts (Zollo, Winter, 2002; Przymus, 2024). Dynamic capabilities enable organizations not only to react to environmental change but also to proactively shape strategic responses by transforming insights into innovation and experiential value (Teece, 2007; Barrales-Molina et al., 2014; Przymus, 2024).

The contemporary literature further indicates that strategic adaptation increasingly depends on the integration of human, technological, and relational capabilities (Warwick, 2025; Alam et al., 2025; Burton, Dickinger, 2025). Leadership supports organizational learning and capability development (Burton, Dickinger, 2025); digital technologies enhance sensing and personalization (Alam et al., 2025); while relational and sustainability-oriented capabilities strengthen authenticity and resilience (Warwick, 2025; Ahachmi et al., 2025). Together, these elements create the conditions necessary for continuous renewal and long-term competitiveness in hospitality environments characterized by uncertainty and turbulence (Teece, 2007; Chasapi et al., 2024).

To summarize the main points discussed in this section, Table 1 provides a comparative overview of the latest research on dynamic capabilities and experience management in the hospitality industry. The analyzed publications demonstrate how leadership, organizational learning, digital transformation, resilience, and customer experience management collectively shape an organization's ability to adapt and innovate in a changing environment.

The comparative synthesis presented in Table 1 highlights a growing convergence within contemporary hospitality research around several core themes: leadership-driven adaptability, digital transformation, experiential personalization, organizational learning, and resilience. Despite methodological and contextual differences, the reviewed studies consistently demonstrate that dynamic capabilities function as critical enablers of strategic renewal and customer experience innovation in turbulent environments (Burton, Dickinger, 2025; Alam et al., 2025; Ahachmi et al., 2025; Przymus, 2024). At the same time, the literature reveals an increasing shift toward interdisciplinary and relational perspectives, integrating technological, emotional, and sustainability-oriented dimensions of hospitality management into broader frameworks of experiential adaptation (Ramirez, 2025; Warwick, 2025; Burton, Dickinger, 2025).

Table 1.
Comparative Synthesis of Contemporary Studies on Dynamic Capabilities and Experience Management in Hospitality

Study	Research Context	Methodology	Main Findings	Theoretical Contribution
Burton, Dickinger (2025)	Hospitality industry during crisis and post-crisis transformation	Conceptual and qualitative analysis	Transformational and participative leadership styles strengthen innovation and organizational adaptability during turbulence	Identifies leadership as a microfoundation of dynamic capabilities in hospitality
	Innovation-oriented hospitality organizations		Learning-oriented leadership cultures foster strategic flexibility and innovation capability development	Connects organizational learning and leadership with dynamic capability formation
Alam et al. (2025)	AI adoption and technology readiness in hospitality	Empirical quantitative study	AI and technological readiness enhance value creation and experiential personalization, though moderated by technological turbulence	Expands dynamic capabilities into digital transformation and AI-enabled service adaptation
Chasapi et al. (2024)	Hospitality firms facing environmental turbulence	Quantitative empirical analysis	Financial and technological capital strengthen organizational agility, while social capital produces mixed effects	Demonstrates the relationship between organizational resources and agility-related dynamic capabilities
Ahachmi et al. (2025)	Gastronomic enterprises in Morocco	Conceptual and empirical analysis	Sensing, seizing, and transforming capabilities enhance organizational resilience and adaptive capacity	Frames resilience as an outcome of dynamic capabilities in gastronomy
Warwick (2025)	Italian fine-dining restaurants	Qualitative interviews and relational analysis	Supplier trust, local sourcing, and collaboration strengthen authenticity and resilience	Introduces relational dynamic capabilities into hospitality experience management
Ramirez (2025)	Michelin-starred and technologically advanced fine dining	Actor-Network Theory qualitative study	Technology, chefs, and ingredients operate as co-actors in experiential co-creation and culinary innovation	Extends experience-economy theory through technological and multisensory mediation
Przymus (2024)	Polish fine-dining restaurants operating under turbulence	Interpretive qualitative case-study approach	Dynamic managerial, marketing, and innovation capabilities jointly support experiential differentiation and customer service adaptation	Develops an integrative model linking dynamic capabilities and customer experience management in hospitality

Source: personal study based on reviewed literature.

Collectively, these findings support the argument that dynamic capabilities should be viewed not as isolated organizational competencies but as interconnected systems of learning and adaptation. This observation provides the foundation for the next section, which explores how dynamic capabilities interact with the principles of the experience economy and customer experience management to create experiential value and strategic resilience in hospitality organizations.

3. Experience Economy and Customer Experience Management

The concept of the experience economy revolutionized the understanding of value creation in services. Pine and Gilmore (1998, 1999) proposed that economies evolve through successive stages, from commodities to goods, to services, and ultimately to experiences, where organizations "stage" memorable and emotionally engaging encounters for their customers. In this new logic, value lies not in the functional utility of a product or service, but in the subjective meaning created during the interaction between the company, its employees, and its customers. Hospitality, by its very nature, embodies this experiential paradigm: each service encounter offers the potential to transform ordinary consumption into symbolic, affective, and multisensory engagement (Hemmington, 2007; Mossberg, 2008).

3.1. From Service Quality to Experience Staging

In traditional hospitality management, competitive advantage was often associated with tangible attributes such as service reliability, physical environment, and operational efficiency. However, as markets matured, customers began to seek more than satisfaction, they sought immersion, authenticity, and co-creation (Richards, 2021). The fine-dining segment represents the apex of this evolution: meals become curated performances, where storytelling, aesthetics, and sensory design merge into holistic experiences. Chefs and service teams act as "experience choreographers", shaping emotions and memories through visual, auditory, olfactory, and gustatory cues (Przymus, 2024).

Recent research suggests that experience creation in fine dining extends beyond aesthetics to include ethical, technological, and emotional dimensions. Ramirez (2025), drawing on Actor-Network Theory, demonstrates how chefs, machines, and ingredients collaborate as co-actors in the performance of gastronomy. His analysis of Michelin-starred restaurants shows that creativity and innovation are not isolated acts of genius but outcomes of networked agency, a complex interplay between human and non-human actors. Technology becomes a facilitator of imagination, precision, and storytelling, allowing chefs to translate abstract concepts into sensory narratives. This perspective reaffirms the dynamic nature of customer experience: it is not static but continuously shaped by technological mediation and collective learning.

3.2. Customer Experience as a Strategic Resource

In contemporary service management, customer experience has evolved into a form of strategic capital. The ability to design and manage experiences systematically, through what is now referred to as Customer Experience Management (CEM), is increasingly viewed as a dynamic organizational capability (Kandampully et al., 2015). CEM involves orchestrating all touchpoints across the customer journey to create consistency, emotional resonance, and perceived authenticity. In fine dining, this orchestration integrates menu innovation,

ambiance, staff interactions, and even social media storytelling into a coherent experiential strategy (Przymus, 2024).

Warwick (2025) contributes to this discussion by emphasizing relational and supply-chain dimensions of the experience economy. Her study of Italian restaurant managers shows that trust-based supplier relationships and adaptive sourcing strategies constitute relational dynamic capabilities that underpin customer experience. The authenticity and quality of ingredients, secured through local and sustainable partnerships, directly influence the perceived value of dining experiences. This relational perspective bridges internal and external orientations, suggesting that customer experience management depends not only on front-stage interactions but also on back-stage collaboration and innovation in the value network.

3.3. Experience Design, Technology, and Personalization

The digital transformation of hospitality has expanded the boundaries of experiential design. According to Alam et al. (2025), AI adoption and technological readiness enhance value creation by enabling real-time personalization, predictive service, and data-driven storytelling. Dynamic marketing capabilities, such as sensing customer emotions through feedback analysis or customizing menus using AI-based preference modeling, allow fine-dining restaurants to respond to evolving expectations with precision and agility. However, Alam et al. caution that these advantages are moderated by technological turbulence, which requires constant capability renewal to maintain alignment between technology and service ethos.

Emerging technologies such as augmented reality (AR), immersive projection, and sensory data analytics blur the lines between physical and digital experiences. Ramirez (2025) observes that digital tools not only support operational efficiency but also expand the artistic vocabulary of chefs, who can now choreograph visual and auditory cues alongside flavor and texture. Yet this technological creativity also raises a paradox: how to preserve authentic human connection, the core of hospitality, amid digital mediation. The challenge, therefore, lies in balancing efficiency and empathy, automation and artistry.

3.4. Emotional, Ethical, and Sustainable Dimensions of Experience

Beyond entertainment and personalization, contemporary customers increasingly expect experiences to reflect their values. Sustainability, inclusivity, and ethical transparency have become central to experiential satisfaction (Buhalis, Sinarta, 2019). Guests seek not only pleasure but also moral alignment, a sense that their choices contribute to a greater good. Fine-dining establishments have responded by integrating sustainability-oriented innovation into their storytelling: showcasing local farmers, reducing waste, and designing plant-based tasting menus that communicate environmental responsibility. These initiatives exemplify sustainability-driven dynamic capabilities, organizational processes that enable learning, adaptation, and legitimacy in response to social expectations (Ahachmi et al., 2025).

Furthermore, the emotional labor of hospitality staff plays a decisive role in shaping customer experience. Burton and Dickinger (2025) note that leadership styles influence not only innovation outcomes but also employee engagement and emotional climate. Transformational leaders who foster psychological safety and shared purpose enable staff to deliver authentic, emotionally resonant service performances, an essential microfoundation of experiential value. In fine dining, where service interactions are intensely personalized, emotional intelligence becomes as critical as technical excellence.

3.5. Experience Economy as a Dynamic System

From a theoretical perspective, the experience economy can be viewed as a dynamic system of co-creation, continuously shaped by learning, feedback, and environmental turbulence. Each experience represents an adaptive response to changing cultural, technological, and social contexts. In this sense, experience management is itself a dynamic capability, the organizational ability to design, test, and refine emotional and sensory propositions in alignment with shifting market logics. As Teece (2018) suggests, firms capable of continuous sensing and learning transform volatility into creativity and renewal.

In fine dining, this system manifests through iterative cycles of innovation: chefs and managers sense emerging gastronomic trends, seize creative opportunities by redesigning menus or service concepts, and transform the organization by embedding new knowledge into routines. These feedback loops reinforce strategic agility and experiential authenticity, illustrating how dynamic capabilities and the experience economy are mutually constitutive.

4. Integrating Dynamic Capabilities and the Experience Economy in Hospitality

Integrating the frameworks of dynamic capabilities and the experience economy allows for a holistic understanding of how hospitality organizations adapt strategically in turbulent environments. Both perspectives share an underlying premise: that competitive advantage depends on an organization's ability to continuously renew resources, processes, and meanings in response to shifting environmental and social demands. Dynamic capabilities provide the mechanism of adaptation, through sensing, seizing, and transforming, while the experience economy provides the context and direction of this adaptation, emphasizing value creation through emotion, narrative, and participation (Pine, Gilmore, 1999; Przymus, 2024).

In fine dining, these mechanisms are deeply intertwined. Sensing relates to identifying changes in customer expectations, cultural trends, and technological opportunities. Seizing involves designing and staging experiences that align with these insights. Transforming refers to embedding experiential learning into the organization's routines, ensuring long-term

adaptability and authenticity. When enacted together, these processes form a continuous cycle of experiential renewal, a "strategic choreography" that blends operational agility with emotional intelligence.

4.1. The Sensing–Seizing–Transforming Cycle in Experiential Contexts

Recent empirical studies in hospitality underscore how the sensing–seizing–transforming (SST) cycle operates in experiential settings. Alam et al. (2025) emphasize that digital transformation enhances the sensing capability by allowing organizations to capture real-time data on customer preferences, emotions, and behaviors. Artificial intelligence and big-data analytics expand the scope of market sensing from reactive feedback to predictive insight. Burton and Dickinger (2025) show that leadership plays a pivotal role in seizing, mobilizing resources, empowering teams, and fostering innovation under conditions of uncertainty. Finally, Ahachmi et al. (2025) and Przymus (2024) demonstrate that transforming occurs through organizational learning and the codification of experiential knowledge into routines, which reinforces resilience and authenticity.

In fine dining, this process is evident in how restaurants respond to turbulence: chefs sense shifts toward sustainable gastronomy or minimalist aesthetics, seize these trends through new menu concepts and storytelling, and transform their identity through continuous staff learning and customer feedback integration. The SST model thus captures the recursive relationship between strategic agility and experiential co-creation.

4.2. Interaction of Dynamic Capabilities and Experiential Value

Dynamic capabilities provide the structural foundation that enables the orchestration of experiences. Managerial capabilities foster cognitive flexibility and strategic foresight, allowing leaders to interpret ambiguous market signals. Marketing capabilities connect these insights to customer expectations through storytelling and brand management. Innovation capabilities, finally, transform ideas into tangible experiences through service design, technological application, and aesthetic experimentation (Przymus, 2024; Ramirez, 2025).

These three domains interact in a synergistic way: managerial cognition enables strategic direction, marketing agility aligns customer understanding with brand narrative, and innovation translates strategy into multisensory and emotional form. As shown in recent research (Chasapi et al., 2024; Warwick, 2025), the quality of interaction among these capabilities determines whether experiential innovations are scalable, authentic, and sustainable.

To clarify how these domains operate in hospitality settings and how they translate into experiential outcomes, Table 2 summarizes the key components of managerial, marketing, and innovation capabilities and their specific implications for Customer Experience Management.

Table 2.
Domains of Dynamic Capabilities and Their Relation to Customer Experience Management in Hospitality

Domain of Dynamic Capability	Dynamic Capabilities and Their Relation to Customer Experience Management in Hospitality	
	key components	**implications for Customer Experience Management**
Managerial	Cognitive flexibility, leadership, emotional intelligence, knowledge integration, team learning	Shapes the organizational culture of hospitality; empowers employees to deliver emotionally engaging, authentic service; fosters learning and innovation during crises (Burton, Dickinger, 2025).
Marketing	Market sensing, storytelling, CRM, data analytics, brand agility	Enables personalized and value-driven experiences; integrates sustainability and ethics into brand narrative; connects digital insights with human interaction (Alam et al., 2025; Warwick, 2025).
Innovation	Service design, process reconfiguration, technological enhancement, creative experimentation	Drives experiential differentiation through multisensory design and technological artistry; allows for rapid adaptation of offerings in response to turbulence (Ramirez, 2025; Przymus, 2024; Ahachmi et al., 2025).

Source: personal study.

The relationships presented in Table 2 demonstrate that dynamic capabilities in hospitality should not be understood as isolated managerial functions but as interconnected mechanisms supporting experiential value creation. Managerial, marketing, and innovation capabilities collectively shape the organization's ability to sense environmental change, personalize customer interactions, and sustain authenticity under turbulent conditions. Their integration enables hospitality firms not only to respond adaptively to crises and technological transformation but also to continuously redesign emotionally engaging and strategically differentiated customer experiences.

4.3. Organizational Agility and Experiential Resilience

The integration of dynamic capabilities and customer-experience management also clarifies the mechanisms of organizational resilience. Agility in hospitality is not only operational but also emotional and symbolic. Organizations must manage uncertainty while preserving the authenticity and intimacy that define hospitality (Montargot et al., 2022). Resilient firms exhibit *experiential continuity*, the ability to maintain their brand identity and emotional resonance even when external conditions change.

Ahachmi et al. (2025) argue that resilience emerges when sensing and seizing are underpinned by cultural intelligence and stakeholder collaboration. Warwick (2025) extends this idea by showing that relational capabilities, trust, communication, and shared purpose, anchor experiential quality during crisis recovery. In this sense, resilience represents the "transform" phase of dynamic capabilities, where organizations integrate learning from turbulence into the ongoing redefinition of the customer experience.

4.4. Conceptual Integration Model

Figure 1 presents the conceptual model integrating dynamic capabilities and the experience economy in turbulent hospitality environments. It conceptualizes the firm as a dynamic system operating at the intersection of three interrelated domains, managerial, marketing, and innovation capabilities, each influencing customer-experience outcomes through the sensing–seizing–transforming mechanism. The outer layer represents environmental turbulence (crises, digitalization, sustainability pressures), which triggers capability activation. The inner core represents customer experience management, encompassing emotional engagement, authenticity, and co-creation.

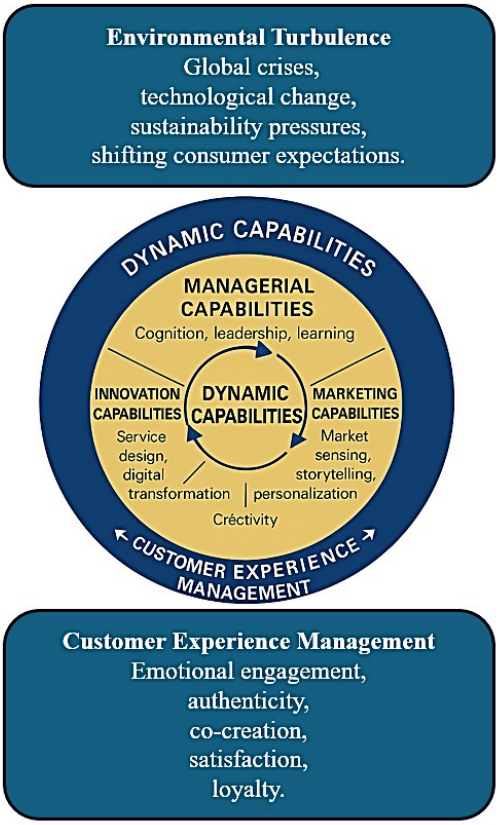

Figure 1. Integration of Dynamic Capabilities and the Experience Economy in Turbulent Hospitality Environments.

Source: personal study.

The conceptual model presented in Figure 1 illustrates that strategic adaptation in hospitality emerges through the continuous interaction between environmental turbulence, dynamic capabilities, and customer experience management. Rather than functioning as linear processes, sensing, seizing, and transforming operate as recursive and mutually reinforcing mechanisms that connect organizational learning with experiential value creation. The model additionally emphasizes that customer experience is not merely an outcome of adaptation but also a source of feedback and strategic renewal, enabling hospitality organizations to transform uncertainty into innovation, resilience, and long-term experiential differentiation.

5. Integrating Dynamic Capabilities and the Experience Economy in Hospitality

5.1. Discussion

This review demonstrates that dynamic capabilities and the experience economy are not separate theoretical paradigms but mutually reinforcing lenses for understanding strategic adaptation in hospitality. The dynamic-capabilities framework explains *how* organizations renew themselves, while the experience-economy perspective clarifies *why* and *toward what ends* such renewal occurs, namely, to create meaningful, memorable, and value-rich customer experiences. Together, they form an integrated theory of experiential adaptation, where innovation, learning, and emotion converge as sources of competitive advantage.

The synthesis of recent studies (Burton, Dickinger, 2025; Alam et al., 2025; Ahachmi et al., 2025; Chasapi et al., 2024; Warwick, 2025; Ramirez, 2025) indicates that turbulence, whether economic, technological, or environmental, no longer functions merely as a disruptive force but as an accelerator of learning and innovation. Crises expose the rigidity of existing routines but also reveal the organization's latent capacity for experimentation and reinvention. The fine-dining sector, traditionally associated with exclusivity and ritualized service, has evolved into a dynamic ecosystem of sensory innovation, ethical reflection, and digital mediation.

Burton and Dickinger (2025) highlight leadership as the key microfoundation that enables the transformation of turbulence into creative opportunity. Leaders who promote participative culture, experimentation, and trust activate dynamic capabilities across managerial, marketing, and innovation domains. Alam et al. (2025) expand this view to the digital realm, demonstrating how technology readiness and AI adoption enhance value creation by enriching the organization's sensing capacity and decision-making agility. Similarly, Ahachmi et al. (2025) and Chasapi et al. (2024) provide empirical validation that the development of dynamic capabilities is closely linked to resilience and organizational agility, two constructs that underpin long-term competitiveness in hospitality.

These findings support and extend the conceptual model proposed in Section 4. The sensing–seizing–transforming (SST) cycle emerges as a process of continuous experiential renewal: sensing market shifts through technological and emotional intelligence, seizing opportunities by designing innovative service experiences, and transforming the organization through reflective learning. Importantly, this model reframes the customer experience not as a passive outcome but as an *active learning feedback loop*, a mechanism through which organizations collect insights, test hypotheses, and strengthen their adaptive capabilities over time.

Thus, the integration of dynamic capabilities with the experience economy moves beyond theoretical juxtaposition; it proposes an experiential theory of organizational adaptation. In fine dining, this manifests as the ability to translate turbulence into aesthetic, emotional,

and social innovation, balancing heritage with novelty, efficiency with empathy, and digitalization with authenticity.

5.2. Theoretical Implications

From a theoretical standpoint, this paper contributes to the dynamic-capabilities literature in three main ways.

First, it extends Teece's (2007) framework by situating sensing, seizing, and transforming within an experiential logic of value creation. Whereas traditional applications of dynamic capabilities emphasize technological innovation and market performance, this study demonstrates their relevance to emotional, cultural, and aesthetic dimensions of organizational renewal. This integration responds to calls for a broader understanding of how intangible and symbolic resources contribute to strategic resilience (Helfat, Martin, 2015; Przymus, 2024).

Second, it advances the microfoundations perspective by emphasizing leadership, cognition, and emotional intelligence as antecedents of dynamic capabilities in hospitality (Burton, Dickinger, 2025). This aligns with the emerging view that dynamic capabilities are enacted through individual agency and social learning rather than structural routines alone. In the hospitality context, where service interactions and team creativity are central, these human-centered foundations are particularly salient.

Third, it contributes to the experience-economy literature by positioning Customer Experience Management (CEM) as a *dynamic capability in itself*, a system of routines, technologies, and interactions that allows organizations to continuously design, test, and refine emotional value propositions. This reframing bridges the gap between operational management and experiential strategy, offering a unified model for analyzing organizational adaptation under turbulence.

5.3. Managerial Implications

For practitioners, the integration of dynamic capabilities and customer-experience management offers five actionable insights for building strategic agility and experiential excellence: (1) cultivating adaptive leadership, (2) investing in digital and data-driven sensing, (3) embedding sustainability and ethics into experience design, (4) strengthening relational networks and (5) institutionalizing experiential learning.

Cultivating adaptive leadership means fostering a managerial mindset oriented toward transformation, empowerment, and learning. Leaders who combine strategic vision with emotional intelligence can better interpret turbulence and translate uncertainty into innovation. Transformational leadership, characterized by trust, communication, and psychological safety, creates the foundation upon which teams can experiment and deliver authentic, emotionally resonant service (Burton, Dickinger, 2025).

Investing in digital and data-driven sensing requires organizations to strengthen their technological infrastructure while maintaining human empathy at the core of the experience. Artificial intelligence and data analytics allow hospitality managers to understand customer expectations in real time and anticipate emerging needs. Yet, as Alam et al. (2025) emphasize, technology should support, not replace, the emotional and narrative coherence of the hospitality experience.

Embedding sustainability and ethics into experience design reflects a growing demand for environmentally and socially responsible gastronomy. Fine-dining restaurants increasingly integrate ethical sourcing, waste reduction, and community engagement into their storytelling. These actions embody sustainability-oriented dynamic capabilities, aligning the organization's value proposition with social legitimacy and long-term competitiveness (Warwick, 2025; Ahachmi et al., 2025).

Strengthening relational networks highlights the importance of collaboration and stakeholder trust. Relationships with local producers, cultural partners, and digital service providers extend the firm's capacity to sense and seize new opportunities, while ensuring authenticity and resilience during crises. Relational dynamic capabilities therefore complement managerial and marketing ones, linking supply-chain innovation with experiential authenticity (Warwick, 2025).

Finally, institutionalizing experiential learning transforms customer feedback and internal reflection into systematic knowledge. Hospitality organizations that capture and codify experiential insights, through debriefs, storytelling archives, or data dashboards, develop collective memory and adaptive intelligence. These learning routines ensure that every service encounter contributes to the organization's evolution and strengthens its ability to transform turbulence into creative renewal (Przymus, 2024).

Taken together, these five practices redefine hospitality management from reactive service delivery to proactive experience orchestration. Managers become curators of meaning who balance digital precision with human warmth, strategic foresight with sensory design, and efficiency with empathy. In this sense, fine-dining restaurants can be viewed as agile learning systems, organizations that continuously translate uncertainty into opportunity and innovation.

5.4. Future Research Directions

Building on the conceptual synthesis presented in this paper, several promising directions emerge for future research on dynamic capabilities and customer experience in hospitality. The first area concerns the empirical validation of the experiential adaptation model proposed here. While this paper provides a theoretical framework, further studies should operationalize its constructs and test them using both quantitative and mixed-method approaches. Comparative research across different hospitality segments, such as fine dining, boutique hotels,

and experiential tourism, could reveal how specific configurations of managerial, marketing, and innovation capabilities drive adaptation and customer value creation.

A second avenue relates to the longitudinal study of digital transformation and emotional intelligence. As artificial intelligence and automation increasingly shape customer interactions, researchers should examine how technological sensing and human empathy co-evolve as complementary dynamic capabilities. Long-term studies could illuminate how digital maturity and managerial cognition interact to sustain innovation and experiential authenticity over time.

Another line of inquiry concerns the cross-cultural dynamics of experiential capabilities. Since hospitality practices are deeply embedded in local traditions, values, and aesthetics, future research should explore how national cultures and institutional contexts influence the formation and enactment of dynamic capabilities. Investigating fine-dining innovation in diverse cultural settings, from Nordic minimalism to Mediterranean conviviality, could enrich theoretical understanding of authenticity and storytelling as culturally situated phenomena.

A fourth direction involves the interdisciplinary expansion of the experience economy framework. Bridging hospitality research with psychology, design, and neuroscience could deepen insight into the cognitive and affective mechanisms through which customers perceive, remember, and assign meaning to experiences. Such integration would strengthen the microfoundations of customer experience and extend the dynamic-capabilities paradigm into behavioral and sensory domains.

Finally, there is a growing need to examine sustainability and resilience as learning systems. Future work could investigate how environmental responsibility, social inclusion, and ethical entrepreneurship evolve as dynamic capabilities that enhance adaptive capacity and stakeholder trust. Exploring these themes through the lens of regenerative hospitality and circular gastronomy would illuminate how organizations not only survive but also contribute positively to their communities and ecosystems.

Together, these directions outline a rich agenda for advancing theory and practice. They invite scholars to adopt longitudinal, comparative, and interdisciplinary approaches to understanding how dynamic capabilities and experiential strategies coalesce in shaping the future of hospitality.

5.5. Concluding Remarks

In turbulent environments, the hospitality industry must balance agility with authenticity, and innovation with empathy. The integration of dynamic capabilities and the experience economy provides a strategic blueprint for achieving this equilibrium. By developing managerial, marketing, and innovation capabilities that are attuned to both technological and emotional signals, fine-dining organizations can transform crises into opportunities for creative renewal.

Ultimately, as this review suggests, strategic adaptation in hospitality is as much an artistic process as it is a managerial one, a continuous choreography of learning, sensing, and storytelling that sustains meaning, memory, and value in an uncertain world.

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STRATEGIC CONNECTIVITY FOR SMART CITY POLICY: A THEORETICAL EXTENSION OF GIFFINGER'S MODEL

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Purpose: This paper extends Giffinger's Smart City model by integrating strategic connectivity to explain how cross dimensional interactions support coherent strategy formulation and policy coordination in urban management systems.
Design/methodology/approach: The study employs a qualitative, critical literature review of sources on smart cities and connectivity, supported by secondary data and illustrative case examples to contextualise the conceptual extension of Giffinger's model.
Findings: The analysis shows that connectivity acts as a transversal, integrative layer in smart cities, enabling coordination and interoperability across technological, organisational, and social subsystems within all six dimensions of Giffinger's model. When implemented in a fragmented or purely technical way, without coherent governance and stakeholder integration, connectivity limits the effectiveness, sustainability, and participatory quality of smart city development.
Research limitations/implications: This study is limited by reliance on secondary sources, highlighting the need for future research using primary data and comparative empirical analysis.
Practical implications: The findings suggest that policymakers should move from fragmented, technology-centered initiatives toward integrated connectivity strategies embedded in governance frameworks to improve service efficiency, stakeholder coordination, and the overall performance of smart city development.
Social implications: The findings indicate that treating connectivity as an integrative and socially embedded dimension of smart city development can enhance citizen participation, reduce digital exclusion, and improve quality of life by enabling inclusive, transparent, and responsive urban governance and services.
Originality/value: This paper's originality lies in conceptualising connectivity not merely as technical infrastructure but as a transversal, integrative dimension that extends Giffinger's smart city model by explicitly linking technological, organisational, and social systems, offering value to scholars and urban policymakers concerned with coherent and human centred smart city governance.
Keywords: Connectivity, Smart City, Giffinger's Model, Strategic Management.
Category of the paper: Research paper.

1. Introduction

A city belongs to the group of public sector organisations and is oriented towards the provision of public goods and services. Consequently, it requires an efficient system of governance, both in functional and institutional terms (Stawasz, 2016). It is also increasingly emphasised that cities rely to a growing extent on advanced institutional capacities, democratic governance, and effective management. These capabilities are required to address increasingly complex and interrelated economic, social, and environmental challenges, while simultaneously benefiting from new technological opportunities (LSE). A defining characteristic of contemporary strategic planning in urban contexts is its evolution into an integrative and context-sensitive approach that coordinates land use, infrastructure, governance, and environmental objectives through collaborative and adaptive frameworks supporting urban sustainability, resilience, and social equity (Balsas, Piracha, 2025). Smart city governance constitutes an institutional framework through which public administration, empowered by digital technologies, coordinates regulatory, participatory, collaborative, and decision support functions to deliver public value, enhance transparency and accountability, mitigate technological risks, and steer sustainable urban development within complex socio-technical environments (Pereira et al., 2026). Contemporary smart city governance constitutes one of the most complex areas of reflection on urban development, requiring the integration of technology, communities, and institutional structures into a single, coherent system of action (Firszt, Jabłoński, 2023).

2. The city in the context of smart development

The discussion begins with a clarification of the concept of the city, followed by a brief outline of the historical evolution of European cities. The term ‘city’, derived from the notion of a place, is defined as “a large, densely and deliberately built-up area” (PWN). A city is a product of civilisation and represents a specific form of population concentration within a defined space, shaped by the historical process of the deepening social division of labour (Ginsbert-Gebert, 1984). Since the earliest stages of civilisational development, cities have served as sites of accumulation of socio-economic activities and phenomena, enabling the satisfaction of both existential and social needs of urban communities (Stawasz, 2016). Depending on their size, cities have assumed leadership roles either at the regional level, in the case of large cities, or at the local level, in the case of smaller urban centres.

The earliest cities and the first organised communities under the rule of early authorities emerged in areas that today belong to Iraq, Syria, Lebanon, and Israel (Kostrzewa, 2013).

The oldest settlements exhibiting urban characteristics, such as Çatal Höyük and Jericho, initiated the urbanisation process of the Near East, which intensified during the fourth and third millennia BCE in Mesopotamia, the Indus Valley, and along the Nile. This process led to the formation of complex spatial and social structures. In the European context, urban development began in the Aegean and Greek regions, where from the Minoan period through the Hellenistic era cities evolved from spontaneous settlements into planned polis structures based on deliberate urban composition. This tradition was subsequently adopted and transformed by the Etruscans and Romans, whose regular urban layouts and extensive settlement networks became the foundation of urbanisation across large parts of Europe. The collapse of the Roman Empire, followed by the development of medieval and early modern cities, resulted in a highly differentiated morphology of European cities, which have continued to evolve under the influence of political, economic, social, and technological factors.

2.1. Smart city concept

The term ‘smart city’ has a relatively short history in both academic discourse and practical application (Dominiak, Gawkowski, Wasielewski, 2022). It first appeared in 1992 to describe a model of urban development oriented towards technology, innovation, and globalisation, in the publication „The Technopolis Phenomenon: Smart Cities, Fast Systems, Global Networks” by David V. Gibson, George Kozmetsky and Raymond W. Smilor (Moura, de Abreu e Silva, 2021). As the comprehensive definition of the smart city continues to evolve, it is conceptualised in various ways by different authors and organisations. There is no universally accepted definition of the smart city concept. Initially, it was primarily associated with the use of technology by cities, but it is currently understood in a broader, interdisciplinary sense. In recent literature, the term 'smart sustainable city' has also emerged as an extension of the original concept of the 'smart city'. Below, several attempts to conceptualise and describe the smart city are presented.

„A smart city or community aims to improve the well-being of its inhabitants, businesses, visitors, organisations and administrators by providing digital services that contribute to a better quality of life. These smart services can help to better manage resources like energy or water (Borowski, 2020; 2025), to monitor and reduce local traffic and pollution or in the work towards greener ways to light and heat buildings. They can also mean a more interactive and responsive city administration, engagement and participation of citizens in decision and policy-making, safer public spaces and meeting the needs of an ageing population and people with disabilities” (European Union).

„A smart sustainable city is an innovative city that uses ICTs and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects” (UNECE).

„A smart city is a city governed in a wise and informed manner, in which digital and telecommunication technologies are employed to enhance the efficiency of networks and services, improve the quality of life of residents, and ensure sustainable development" (Warsaw).

The term 'smart city' is not defined in a single, universally accepted manner however, a common denominator across most attempts to conceptualise it is the enhancement of residents' quality of life. Different organisations and authors emphasise various aspects, including the efficiency of urban services, competitiveness, quality of life, and the inclusiveness of applied solutions. The evolution of the smart city concept reflects the growing importance of integrating technology with urban policy, sustainable development, and social participation.

3. Methodology

This research was conducted using the desk research method, which relies on existing sources such as books, reports, databases, and internet resources. This approach is generally more cost effective and time efficient than primary research methods, while providing essential background, context, and a foundation for further investigation. Desk research enables access to a wide spectrum of secondary data, including academic publications, industry and government reports, statistical databases, and press materials. Its strength lies in the ability to integrate diverse information sources into a coherent analytical framework. However, the accuracy and reliability of the findings depend on the careful selection, evaluation, and credibility of the sources used (Sułek, Borowski, 2024).

4. Rudolf Giffinger's six dimensions smart city model

One of the most widely recognised smart city frameworks is the concept developed on the basis of benchmarking medium sized European cities by a research team led by Rudolf Giffinger from the Vienna University of Technology. This model identifies six key domains of smart city functioning, namely:

- smart economy (competitiveness), understood as an innovative economy, encompassing such factors as innovation capacity, entrepreneurship, economic promotion, productivity, a flexible labour market, economic internationalisation, and the ability to adapt to change,

- smart people (social and human capital), referring to engaged and empowered citizens, including factors such as educational attainment, willingness to engage in lifelong learning, social and ethnic diversity, flexibility, creativity, international orientation understood as openness to the world, and citizens' participation in public life,
- smart governance (participation), denoting informed and inclusive governance, encompassing factors such as citizen participation in decision making processes, the quality of public and social services, transparency of public authorities, and forward-looking strategic development planning,
- smart mobility (transport and ICT), referring to intelligent mobility systems, including well organised public transport, national and international transport accessibility, the provision of information and communication technology infrastructure, and sustainable, modern, and safe transport systems,
- smart environment (natural resources), relating to environmental quality, including factors such as the attractiveness of natural conditions, pollution levels, environmental protection efforts, and sustainable resource management,
- smart living (quality of life), referring to residents' wellbeing, encompassing factors such as cultural infrastructure, access to healthcare, personal safety, quality of housing infrastructure, access to education, tourism attractiveness, and social cohesion (Smart cities ranking, 2007; Dominiak, Gawkowski, Wasielewski, 2022).

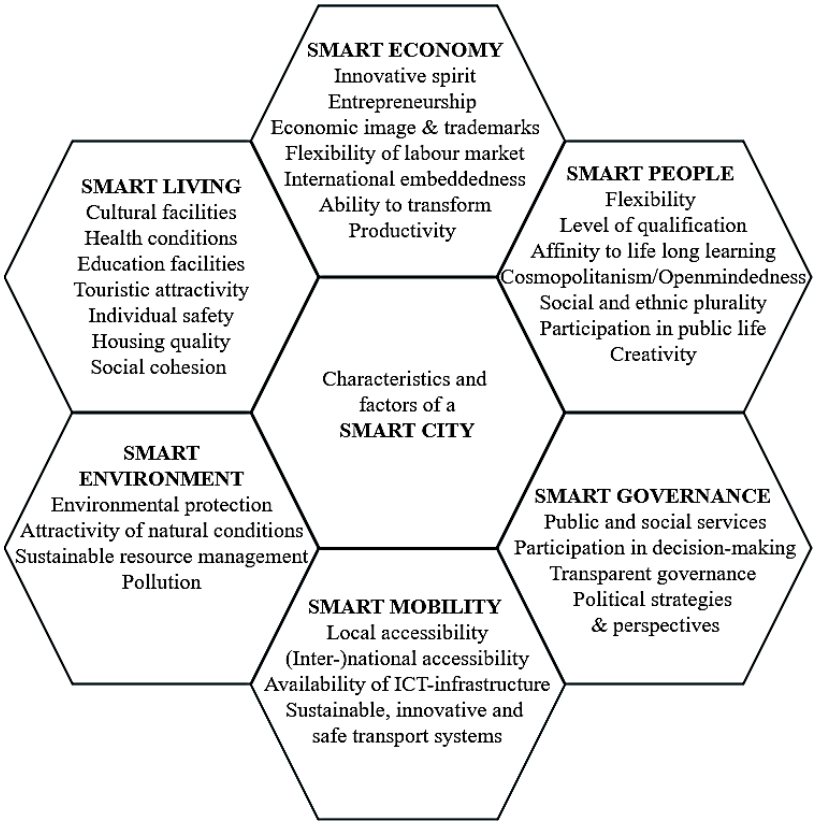

Figure 1. Giffinger's six dimensions: characteristics and factors of a smart city.

Source: Prepared by the authors based on Giffinger et al., 2007.

5. Connectivity as a key dimension of the smart city

The concept of connectivity is defined as „the ability of systems, platforms and applications to be connected to each other" (Oxford). In the context of the smart city, connectivity is implemented through:

- network and telecommunication infrastructure, including fibre optic networks, municipal networks, urban access points, and mobile networks,
- urban sensing infrastructure, comprising sensors, urban actuators, and LPWAN (Low Power Wide Area Network) systems,
- urban data and interoperability platforms, including integrated municipal platforms enabling data exchange and system integration,
- urban mobility services, encompassing intelligent transport systems, micromobility solutions, and shared vehicle systems,
- smart urban energy and environmental infrastructure, including dynamic management of energy demand and supply, smart metering, and real-time environmental monitoring,
- emerging technologies, such as digital twins, edge computing combined with artificial intelligence, and mesh networks (Authors' own elaboration).

5.1. Examples of connectivity applications in smart cities

Connectivity plays an integrative role in German smart cities by linking data, institutions, and users into coherent urban systems. In cities such as Berlin, Hamburg, and Dresden, it underpins smart governance, sustainable mobility, and urban resilience through platforms integrating digital twins, sensor networks, and data-driven decision making (Bichueti et al., 2025).

The city of Porto in Portugal represents a smart city case in which connectivity integrates urban mobility, environmental management, governance, and citizens through digital solutions. Systems such as Andante, real-time transport information, IoT applications, and data-driven platforms support coordinated mobility services, environmental monitoring, and citizen participation, contributing to a more sustainable and interconnected urban system (Baptista, Bezerra, 2025).

Rome exemplifies a smart city where connectivity enables participatory governance by integrating institutions, stakeholders and citizens through digital platforms such as the Consulta Roma Smart City Lab, the Roma Data Platform and the AI assistant Giulia, facilitating coordinated data flows, transparent decision making and co-creation within an inclusive, data-driven urban framework (Romolini, Meleo, Sances, 2025).

5.2. Challenges and risks associated with the implementation of connectivity in smart cities

From a theoretical perspective, connectivity constitutes an integrative analytical category linking technical, organisational and social dimensions, grounded in systems thinking and complexity theory, where relational structures enable information flows, coordinated action and the emergence of new organisational forms. However, as highlighted by Haven, smart city development is constrained by fragmented implementations and insufficient institutional coordination, meaning that connectivity, when not embedded in coherent governance and social frameworks, fails to function as an integrative backbone and instead amplifies interoperability gaps, cybersecurity risks and barriers to effective urban transformation (Haven, 2020). As Borowski notes, digitalization plays a huge role in this effective transformation process (Borowski, 2022).

6. Discussion

The results of the research conducted using the desk research method reveal recurring patterns of fragmentation and integration within urban systems, particularly in the context of connectivity. The conducted review indicates that connectivity is perceived not only as an element of technological infrastructure, but also as a mechanism shaping relationships between governance, society, and economic structures. The obtained results provide a basis for further theoretical considerations of connectivity as a systemic and human-centred phenomenon.

Neuhofer, Magnus and Celuch introduced the „(…) novel term 'Technology-mediated Life Ecosystems' This humancentric ecosystem recognises AI-supported life realities of the end-user that cross and permeate all life domains"(Neuhofer, Magnus, Celuch, 2020, p. 10). This concept reframes connectivity by shifting attention from technology as a tool to technology as a lived environment, where connectivity functions not merely as infrastructure but as a condition enabling complex, interdependent relationships among social, economic and institutional systems.

An important element of the theoretical understanding of connectivity is its role in the transformation of governance and management models. As noted by A. Rzepka, M. Kocot and E. Jędrych, „The 21st century is a time of computerization, digitization, and electronization of flows and virtualization of management activities. The development of IT has contributed to the fact that in the field of management, many activities can be carried out using electronic means of communication, in particular the Internet, without the physical involvement of those involved in the transaction" (Rzepka, Kocot, Jędrych, 2021, p. 346). This finding supports the thesis that connectivity redefines core management categories like presence, control and

coordination, making high connectivity a prerequisite for the shift from hierarchical to network based governance in smart cities.

Connectivity plays a pivotal role in the ongoing transformation of the transport sector, a sector that is fundamental to the functioning of all smart cities. „(…) element of improving the transport system is intelligent systems that can monitor and analyse traffic data and road conditions in real time. Based on this information, they can adjust traffic lights, optimizing the duration of the lights and changing them depending on the current situation. This helps to avoid unnecessary congestion and slowdowns, which lowers fuel consumption and emissions" (Borowski, 2024, p. 178).

7. Summary

Connectivity constitutes a transversal and integrative dimension permeating all six components of Giffinger's smart city model, functioning as the structural logic that binds smart economy, people, governance, mobility, environment and living into a coherent system. It extends beyond technical infrastructure by enabling continuous data flows, coordination among actors and interoperability of urban subsystems, without which economic innovation, participatory governance and efficient mobility remain fragmented. Connectivity supports smart people through digital platforms facilitating learning, participation and creativity, while reinforcing smart environment and smart living via real time monitoring, data□driven resource management and responsive urban services. Consequently, the theoretical extension of Giffinger's model underscores connectivity as the connective tissue conditioning the functionality, maturity and effective governance of contemporary smart cities.

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INFORMATION MANAGEMENT ETHICS AS AN ELEMENT OF THE NON-MILITARY SECURITY OF STATES AND ORGANIZATIONS

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Purpose: This article examines the role of information management ethics in the non-military security of states and organizations. It explores how information governance affects institutional resilience, critical infrastructure protection, and public trust, while identifying risks related to artificial intelligence, dual-use technologies, and state information infrastructure.
Design/methodology/approach: The study employs a qualitative comparative analysis of literature and normative documents in the fields of security, management, technology ethics, and international law. The theoretical considerations are supported by a comparative analysis of artificial intelligence systems, dual-use technologies, and state information infrastructure, representing algorithmic, strategic, and systemic information-related risks. The assessment is based on transparency, accountability, institutional control, proportionality, and resilience.
Findings: The results suggest that threats to non-military security arise primarily from deficiencies in information governance rather than from technology itself. Transparency, accountability, control, and proportionality emerge as key factors shaping security and resilience. The study also proposes a four-dimensional model of ethical information management comprising normative, procedural, control, and cultural dimensions.
Research limitations/implications: The article is theoretical in nature and does not include empirical verification of the proposed model. Further research is needed to examine the implementation of ethical information management principles and their impact on security and institutional resilience.
Practical implications: The proposed model may support the development of information governance systems, security policies, compliance procedures, and ethical standards, particularly in relation to AI, data protection, and cybersecurity.
Social implications: Ethical information management contributes to the protection of citizens' rights, the strengthening of public trust, and greater resilience to hybrid, cyber, and information threats.
Originality/value: The article integrates perspectives from management, security, information ethics, and emerging technologies within a single analytical framework. It highlights the relationship between information management quality and non-military security, while identifying mechanisms through which ethical governance may support institutional resilience.
Keywords: information ethics, information management, non-military security, artificial intelligence, information governance.
Category of the paper: Conceptual Paper / Research Paper.

1. Introduction

The security of the modern state can no longer be analyzed solely in military terms (Burgess, 2007; Kitler, 2011). The development of digital technologies, the globalization of information flows, and the growing dependence of socio-economic systems on information and communication technology (ICT) infrastructure have led to the emergence of non-military security as an important field of study (Kitler, 2011). Hybrid, cyber, and information threats demonstrate that a state may be destabilized without the use of armed force, through information manipulation, disinformation, or disruptions to ICT systems (Franke, 2015).

In this context, information ceases to be merely a resource supporting decision-making processes and becomes an integral element of security infrastructure (Boin, van Eeten, 2013). In management studies, the concept of information governance has gained increasing attention and is understood as a system of principles and mechanisms regulating the information life cycle within an organization (Smallwood, 2019; Singh, 2025). It encompasses both an operational dimension - related to data quality and integrity - and a normative dimension, referring to legal compliance, proportionality, and institutional accountability (Rhodes, 1996; Bovens, 2007).

The development of artificial intelligence and predictive analytics in public administration complicates the relationship between efficiency and accountability (Pasquale, 2015; Clever, 2025). The AI Act (European Parliament and Council, 2024) introduces a classification of AI systems based on their level of risk and imposes requirements regarding transparency and the assessment of their impact on fundamental rights. Consequently, information management becomes an integral component of the regulatory framework that determines the level of security.

At the same time, Regulation (EU) 2021/821 (European Parliament and Council, 2021) extends the responsibilities of states and enterprises with regard to the transfer of dual-use technologies. Analytical and cryptographic technologies may serve both civilian and military purposes (Rath, Ischi, Perkins, 2014), which necessitates the implementation of risk identification and assessment procedures. In this context, ethical information management becomes a tool for the prevention of strategic risks (Floridi, 2013).

Despite the growing body of research on cybersecurity and artificial intelligence, there is still a lack of in-depth analysis of information management ethics as a component of non- military security from a management perspective (Floridi, 2013). The aim of this article is to demonstrate that the integration of the principles of proportionality, transparency, accountability, and compliance into information governance systems enhances institutional resilience and mitigates the risk of informational destabilization (Boin, van Eeten, 2013; Power, 2007).

The foregoing considerations justify the need to examine non-military security from a management perspective, in which the quality of information governance constitutes a key analytical category (Rhodes, 1996).

2. Non-Military Security from a Management Perspective

2.1. Non-Military Security as a Governance Challenge

The concept of non-military security has evolved alongside the expansion of the spectrum of threats extending beyond the traditional military paradigm (Burgess, 2007). The literature emphasizes that the modern state functions as a complex organizational system whose stability depends on the effective functioning of social, economic, and informational processes (Kitler, 2011). Security is understood as the ability to maintain the continuity of critical structures and functions under conditions of disruption (Boin, van Eeten, 2013; OECD, 2024).

From a management perspective, non-military security may be interpreted as an outcome of the quality of governance, understood as a system of oversight, accountability, and control of decision-making processes (Rhodes, 1996; Bovens, 2007). Institutional resilience stems not only from the redundancy of technical infrastructure but also from the quality of the information upon which decisions are based (Boin, van Eeten, 2013). In the digital environment, information becomes both a strategic resource (Barney, 1991) and a potential source of risk (Floridi, 2013).

Disruptions in the flow of information - resulting from disinformation, manipulation, or failures of information and communication technology (ICT) systems - may lead to a loss of decision-making capacity and the erosion of public trust (Franke, 2015). In this sense, non- military security is closely linked to the quality of information management. Ethical standards for data processing, procedural transparency, and control mechanisms constitute an integral part of security infrastructure (Bovens, 2007; Power, 2007).

2.2. Information as Security Infrastructure

In the context of digitalization, information infrastructure underpins the functioning of other critical systems, including energy, transportation, and financial systems (Boin, van Eeten, 2013). Administrative systems based on digital data processing, combined with analytical tools employed in crisis management, constitute a complex decision-making architecture, the disruption of which may result in destabilization without the use of armed force (Franke, 2015).

From this perspective, information management ethics performs an infrastructural function (Floridi, 2013). A lack of transparency, uncontrolled data processing, or the instrumental use of information may result in the loss of legitimacy of public institutions (Hausner, 2008). Public trust thus becomes an essential component of systemic security (Kitler, 2011).

2.3. Governance as a Security Mechanism

Governance in the public sector encompasses regulatory mechanisms, oversight procedures, and systems of accountability (Rhodes, 1996; Bovens, 2007). In the digital environment, information governance must integrate both technical and normative dimensions (Smallwood, 2019). European regulations, such as the AI Act (European Parliament and Council, 2024) and Regulation (EU) 2021/821 (European Parliament and Council, 2021), emphasize the need for risk assessment, documentation of decision-making processes, and control over technology transfers. Consequently, information management becomes an integral component of compliance and risk management (Power, 2007), and its quality directly affects the level of non-military security (Boin, van Eeten, 2013).

Since non-military security depends on the quality of information processes, a deeper understanding of information as a strategic resource of states and organizations is required (Barney, 1991).

3. Information as a Strategic Resource for States and Organizations

The ongoing digitalization of public administration is transforming information into a strategic resource (Barney, 1991). In a data-driven economy, organizational advantage depends not only on access to tangible resources but also on the quality of information and the ability to process it effectively (Barney, 1991; Smallwood, 2019). In the public sector, this translates into the quality of administrative decision-making, the effectiveness of crisis management, and the protection of critical infrastructure (Boin, van Eeten, 2013; Kitler, 2011).

Decisions based on incomplete, outdated, or distorted data lead to deficiencies in the decision-making process, which, in the context of non-military security, may generate systemic consequences (Kitler, 2011). Digital transformation also shifts responsibility from the level of individual administrative decisions to that of information systems and algorithmic processes (Pasquale, 2015). Artificial intelligence systems used in public administration directly affect the legal status of citizens, thereby increasing the importance of transparency and oversight (European Parliament and Council, 2024; Bovens, 2007).

3.1. Information Capital and Systemic Resilience

Institutional resilience refers to the ability to maintain critical functions under conditions of disruption (Boin, van Eeten, 2013). In the digital environment, it depends on the quality of the information architecture, including data integrity, system security, and the clear allocation of responsibility (Smallwood, 2019; Bovens, 2007). Technical redundancy alone is not sufficient unless it is supported by a coherent system of governance (Rhodes, 1996).

The key elements include:

- the clear assignment of responsibility for data (Bovens, 2007),
- access control and auditing of data processing activities (Power, 2007),
- compliance with national and European Union regulations (European Parliament and Council, 2016; European Parliament and Council, 2022),
- the systematic assessment of technological risks (European Parliament and Council, 2024; Power, 2007).

The lack of these mechanisms increases susceptibility to abuse, data breaches, and the instrumentalization of information for purposes that conflict with the public interest (Floridi, 2013; Pasquale, 2015).

3.2. The Regulatory Dimension and Dual-Use Technologies

The strengthening of the regulatory framework within the European Union underscores the strategic nature of information. The AI Act imposes obligations regarding risk assessment and the documentation of decision-making processes in high-risk systems (European Parliament and Council, 2024). Regulation (EU) 2021/821 extends export controls to dual-use technologies, including information technology solutions (European Parliament and Council, 2021). The GDPR and the NIS2 Directive further reinforce accountability in the areas of data protection and ICT risk management (European Parliament and Council, 2016; European Parliament and Council, 2022).

Dual-use technologies - including analytical and cryptographic systems - may be employed for both civilian and military purposes (Rath, Ischi, Perkins, 2014). This requires the implementation of procedures for identifying sensitive technologies, assessing transfer risks, and monitoring international cooperation (European Parliament and Council, 2021). On this basis, information management becomes an element of strategic security (Franke, 2015; Kitler, 2011).

The strategic nature of information implies the need for its normative conceptualization, which has led to the emergence of information management ethics as a distinct analytical category within management studies (Floridi, 2013; Crane, Matten, 2016).

4. Information Management Ethics as a Normative Category

In management studies, ethics has traditionally been examined in the context of organizational responsibility toward stakeholders and corporate governance (Freeman, 1984; Crane, Matten, 2016). However, the digitalization of decision-making processes has necessitated the recognition of information management ethics as a distinct area of inquiry (Floridi, 2013; Ribeiro et al., 2025). It encompasses norms governing the collection, processing, and use of data, as well as responsibility for the consequences of decisions based on digital systems (Pasquale, 2015).

In the information society, information shapes both institutional and social relationships (Floridi, 2013; Ribeiro et al., 2025). Managing information therefore entails managing its impact on citizens and stakeholders (Freeman, 1984). Information management ethics is not merely a moral category but also a regulatory mechanism that influences the level of systemic security (Burgess, 2007; Kitler, 2011).

In the public sector, particular importance is attached to the principle of proportionality, according to which data processing must be appropriate and proportionate to the public purpose it serves (European Parliament and Council, 2016). European regulations - particularly the GDPR and the AI Act - strengthen the obligation to conduct risk assessments, document decision-making processes, and ensure algorithmic transparency (European Parliament and Council, 2016; European Parliament and Council, 2024). Information governance thus becomes a system that integrates ethical standards with operational practice (Smallwood, 2019; Bovens, 2007).

4.1. Accountability and Transparency

Accountability refers to the ability to assign responsibility for decisions and to ensure the existence of control mechanisms (Bovens, 2007). In the context of information management, it includes the identification of the entity responsible for data, the ability to reconstruct the decision-making process, and the availability of information to supervisory authorities (Rhodes, 1996).

A lack of transparency leads to the emergence of "black-box decision-making", in which decisions of public significance are made without the possibility of verification (Pasquale, 2015). In the context of information threats, deficits in transparency increase the vulnerability of institutions to a loss of legitimacy and destabilization (Franke, 2015; Floridi, 2013).

4.2. Information Ethics and Risk Management

Information management is associated with multidimensional risks, including data protection breaches, algorithmic errors, information manipulation, and the uncontrolled transfer of dual-use technologies (Rath, Ischi, Perkins, 2014; Pasquale, 2015). Regulations such as

Regulation (EU) 2021/821 require the implementation of due diligence procedures and compliance systems (European Parliament and Council, 2021).

The integration of ethics into risk management reduces the likelihood of destabilizing events (Power, 2007; Mokander, Floridi, 2024). Responsible information governance mitigates the risks of critical infrastructure data breaches, systemic algorithmic discrimination, and the strategic consequences of technology transfers (Floridi, 2013; Boin, van Eeten, 2013).

4.3. The Cultural Dimension

Formal regulations do not guarantee effectiveness unless they are accompanied by an organizational culture grounded in responsibility (Schein, 2010). The internalization of ethical norms by members of an organization strengthens institutional resilience (Boin, van Eeten, 2013). Information management ethics thus becomes an element of a security culture that encompasses awareness of information-related threats, a willingness to report violations, and responsible leadership (Hausner, 2008; Kitler, 2011).

The conceptualization of information management ethics as a normative category makes it possible to identify the fundamental mechanisms governing information processes within organizations and state structures. However, this perspective remains primarily theoretical and requires further development through reference to specific technological domains in which the tensions between efficiency, control, and accountability become most apparent.

For this reason, a comparative analysis of selected areas of digital transformation is undertaken to operationalize the adopted analytical categories and identify recurring patterns of risk. The analysis focuses on artificial intelligence systems, dual-use technologies, and state information infrastructure.

5. Qualitative Study: Operationalization and Comparative Analysis of Information Management Risks

To further develop the adopted theoretical assumptions, a qualitative comparative study was conducted based on a content analysis of academic literature, legal regulations, and publications concerning information security. The study adopts an exploratory and interpretive approach and seeks to identify recurring risk patterns associated with information management in the context of digital transformation, with particular emphasis on the development of artificial intelligence systems and their implications for information security (OECD, 2024; Zhang, Zhao, Meng, Lai, Chen, 2025).

The starting point of the analysis was the operationalization of analytical categories derived from the preceding theoretical considerations. It was assumed that the key dimensions for assessing the quality of information governance include the transparency of data-processing

processes, the ability to assign responsibility for decisions, the effectiveness of institutional control mechanisms, the appropriateness of data processing in relation to public objectives, and the impact of information systems on institutional resilience (Bovens, 2007; Boin, van Eeten, 2013; European Parliament and Council, 2016). The application of these categories enables a shift from a normative analysis to a comparative approach, allowing for the identification of recurring risk mechanisms.

The selection of research cases was theoretical in nature and focused on areas of particular significance for non-military security (Kitler, 2011).

To ensure analytical coherence, the study focuses on three areas that represent distinct but complementary dimensions of information-related security risks. Artificial intelligence systems illustrate algorithmic risks associated with automated decision-making, opacity, and accountability deficits. Dual-use technologies represent strategic risks arising from the transfer and potential misuse of technologies that may serve both civilian and military purposes. State information infrastructure reflects systemic risks connected with the continuity and resilience of critical public functions dependent on digital information systems.

Together, these areas capture three fundamental levels at which information management influences non-military security: decision-making processes, technology governance, and the operational functioning of state structures. The objective was not to provide an exhaustive overview of all information-related threats, but rather to identify recurring governance mechanisms across different categories of risk.

Other important domains, including cybersecurity management, disinformation governance, and critical data platforms, were not treated as separate analytical categories because they operate as cross-cutting phenomena within the examined areas. Cybersecurity is embedded in the governance of information infrastructure, disinformation directly affects the quality and integrity of information processes, while critical data platforms constitute components of broader information ecosystems. Their exclusion as standalone cases was therefore intended to avoid conceptual overlap and to maintain a clear comparative framework.

The analysis covered artificial intelligence systems used in decision-making processes, dual-use technologies, and state information infrastructure, which constitutes the foundation of contemporary socio-economic systems. Accordingly, each of the selected areas represents a distinct type of risk - algorithmic, strategic, and systemic - thereby enabling a multidimensional analysis of information management challenges within the broader framework of non-military security.

The analysis of artificial intelligence systems indicates that their growing importance in public administration enhances the efficiency of data processing while simultaneously creating tensions between operational effectiveness and institutional accountability (Pasquale, 2015; European Parliament and Council, 2024; Tallam, 2025).

It should be noted, however, that artificial intelligence systems are not a homogeneous category. The level of risk associated with their use depends on both the functional characteristics of the system and the context in which it is deployed. In accordance with the AI Act, different regulatory requirements apply to systems presenting limited, high, or unacceptable levels of risk (European Parliament and Council, 2024).

Particular ethical and governance challenges arise in high-risk applications used within public administration, especially where AI supports decisions concerning access to public services, social benefits, migration procedures, law enforcement, or critical infrastructure management. In such contexts, limitations in explainability and transparency may significantly affect the ability of individuals to understand, challenge, or verify administrative decisions. By contrast, AI systems used for routine administrative support or information management generally pose lower risks to fundamental rights and institutional legitimacy.

Consequently, the concepts of "black-box decision-making" and "automated accountability" should be understood primarily in relation to high-impact decision environments, where algorithmic outputs may substantially influence the legal status, rights, or obligations of individuals.

The limited transparency of algorithms makes it difficult to reconstruct the decision-making process, thereby weakening the ability to assign responsibility. As a consequence, a phenomenon of "automated accountability" emerges, whereby decisions of public significance are increasingly made through processes that are difficult to verify, thereby heightening the risk of systemic errors and undermining public trust (Pasquale, 2015; Floridi, 2013; McCormack, Huyskes, Lewis, Bendechache, 2025).

In the case of dual-use technologies, the key issue is not the technology itself but rather the insufficient effectiveness of regulatory mechanisms designed to control its use (Rath, Ischi, Perkins, 2014). The dual nature of these technologies means that the boundary between civilian applications and potentially military or repressive uses remains fluid. European Union regulations, particularly Regulation (EU) 2021/821, introduce obligations related to risk assessment and the implementation of due diligence procedures; however, their effectiveness depends on integration with organizational management practices (European Parliament and Council, 2021; Power, 2007). In this area, the problems of dispersed accountability and the limited effectiveness of control mechanisms in a transnational environment are particularly evident.

The analysis of state information infrastructure highlights its fundamental importance for systemic stability. Data-processing systems constitute the foundation for the functioning of other critical infrastructure sectors, meaning that their disruption may lead to cascading effects (Boin, van Eeten, 2013). At the same time, a tension exists between the need for data transparency and openness and the necessity of protecting sensitive information. Excessive data accessibility increases vulnerability to cyber threats, whereas excessive restrictions on data access may reduce the efficiency and transparency of public administration (Franke, 2015).

The results of the comparative analysis are presented in Table 1., which synthesizes the relationships between the informational function of each area, the type of risk involved, and the degree to which key governance categories are implemented.

Table 1.
Comparative Analysis of Information Management Across the Examined Areas

Area	Informational Function	Type of Risk	Transparency	Accountability	Control	Proportionality	Impact on Resilience
AI	Decision automation	Algorithmic	Low	Limited	Moderate	Problematic	High
Dual-use	Technology transfer	Strategic	Moderate	Dispersed	Low-moderate	Critical	High
Information Infrastructure	Systems integration	Systemic	Variable	Formally high	High	Conflicting	Very high

Source: Author's own.

The interpretation of the results indicates that the key factor determining the level of risk is not the degree of technological advancement itself, but rather the quality of information management (Boin, van Eeten, 2013; Power, 2007; Challenges in AI Governance, 2025). As system complexity increases, there is a tendency toward reduced transparency and weakened accountability mechanisms. This trend is particularly evident in artificial intelligence systems, where deficits in transparency lead to the emergence of decision-making structures with limited controllability (Bovens, 2007; Pasquale, 2015).

The analysis further indicates that accountability constitutes one of the weakest elements of the system, particularly in transnational and technological contexts where responsibility becomes dispersed (Bovens, 2007). In the case of dual-use technologies and AI systems, this problem is structural in nature and cannot be resolved solely through formal regulation. At the same time, the findings suggest that the effectiveness of control mechanisms depends on their integration with organizational processes, implying that formal compliance alone is insufficient to ensure security (Power, 2007).

On this basis, it can be argued that information management ethics functions as a mechanism for reducing systemic risk by integrating normative and operational dimensions (Floridi, 2013). Its importance increases particularly under conditions of high technological complexity, limited transparency, and dispersed accountability. In such circumstances, deficiencies in information governance may lead to systemic destabilization, thereby confirming its crucial role within the structure of non-military security (Franke, 2015; Kitler, 2011).

The analysis conducted indicates that the identified risk mechanisms are systemic and recurring in nature, regardless of the technological characteristics of the areas under examination. This suggests that their source lies not solely in the level of technological advancement but, above all, in the quality of information management and the degree of

integration among normative, procedural, and control mechanisms (Boin, van Eeten, 2013; Power, 2007).

The findings justify the need for a synthetic conceptualization of the relationship between information management ethics and non-military security. In response to this need, the following section proposes a theoretical model that integrates the identified dimensions into a coherent system of information governance (Rhodes, 1996; Smallwood, 2019).

6. A Model of Ethical Information Management as an Element of Non-Military Security

The analysis conducted allows for the conclusion that information management ethics constitutes a structural component of non-military security (Burgess, 2007; Kitler, 2011). On this basis, a model has been proposed that integrates normative, organizational, and systemic dimensions, illustrating how ethical standards are translated into institutional resilience (Boin, van Eeten, 2013; Choung, David, Seberger, 2023).

The model is four-dimensional and comprises:

- The normative dimension - relating to the principles of proportionality, the protection of individual rights, transparency, and accountability (European Parliament and Council, 2016; Bovens, 2007).
- The procedural dimension - encompassing the standardization of data-processing activities, the documentation of decisions, and information quality control (Smallwood, 2019).
- The control dimension – associated with auditing, compliance systems, risk assessment, and oversight mechanisms (Power, 2007).
- The cultural dimension – concerning the internalization of ethical norms and responsible leadership (Schein, 2010).

This approach is consistent with recent proposals concerning responsible AI systems, which emphasize the interdependence of trustworthy AI design, auditability, accountability, and governance as conditions for embedding responsibility throughout the AI lifecycle (Herrera-Poyatos et al., 2025).

The model is systemic in nature because it assumes the interdependence of all dimensions, and the weakening of any one of them leads to the erosion of the entire information security mechanism (Boin, van Eeten, 2013). The integration of these four dimensions within an information governance system enhances institutional resilience and, consequently, strengthens non-military security (Kitler, 2011).

6.1. The Normative Dimension

The normative dimension is grounded in both European Union and national regulations. The AI Act introduces the obligation to assess risks associated with high-risk AI systems (European Parliament and Council, 2024), the GDPR reinforces the principles of data minimization and accountability (European Parliament and Council, 2016), and regulations concerning dual-use technologies impose requirements for controlling technology transfers (European Parliament and Council, 2021). In practice, this entails the need to assess the impact of information systems on fundamental rights and to ensure that data processing remains proportionate to the public purpose it serves (Floridi, 2013).

From a security perspective, normative frameworks reduce the risk of the instrumentalization of technology and strengthen the legitimacy of public decisions (Burgess, 2007).

6.2. The Procedural Dimension

The procedural dimension refers to the technical and organizational principles governing information processing. It encompasses the standardization of procedures, the documentation of algorithmic decisions, and access control mechanisms for data (Smallwood, 2019). The quality and integrity of information determine the reliability of the decision-making process, while their absence may lead to systemic errors of strategic significance (Barney, 1991; Kitler, 2011).

6.3. The Control Dimension

The control dimension encompasses systems of auditing, reporting, and risk assessment (Power, 2007). Due diligence procedures related to technology transfers, data protection impact assessments, and the monitoring of ICT threats constitute essential elements of information risk management (European Parliament and Council, 2021; European Parliament and Council, 2022). These mechanisms reduce the likelihood of destabilizing events (Boin, van Eeten, 2013).

6.4. The Cultural Dimension

Organizational culture determines the effectiveness of formal regulations (Schein, 2010). The internalization of ethical norms, awareness of information-related threats, and responsible leadership strengthen the coherence of the governance system (Hausner, 2008). Without this dimension, compliance procedures may become merely formalized practices lacking real effectiveness (Power, 2007).

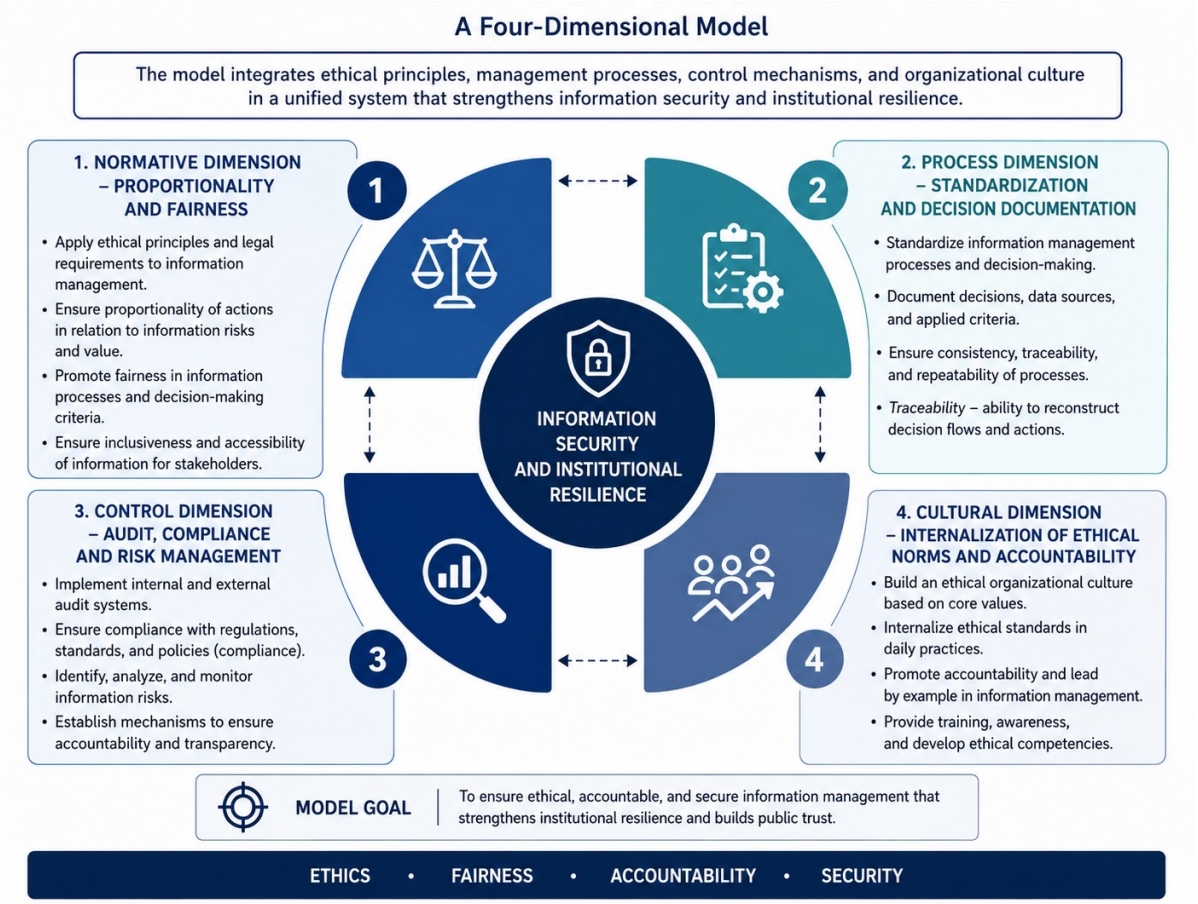

Figure 1. Ethical information management model.

Source: Author's own.

The model presents four complementary dimensions - normative, procedural, control, and cultural - integrated within an information governance system. The combined effect of these dimensions is institutional resilience, which in turn contributes to the non-military security of states and organizations (Boin, van Eeten, 2013; Kitler, 2011).

However, the proposed model requires validation through its application in public management practice and through engagement with contemporary regulatory challenges (European Parliament and Council, 2024).

7. Discussion: Implications for Public Management and Systemic Security

The findings presented indicate that non-military security should not be understood solely as a strategic category analyzed within security studies, but rather as an outcome of the quality of management processes, particularly those related to the processing and use of information (Burgess, 2007; Kitler, 2011). From this perspective, information governance serves as

a mechanism for stabilizing public systems by integrating regulatory, technological, and axiological dimensions (Rhodes, 1996; Floridi, 2013; UNDP, 2025).

The results of the comparative analysis confirm that institutional resilience is largely determined by the quality of information management. Regardless of the specific area under examination—artificial intelligence systems, dual-use technologies, or state information infrastructure—the transparency of decision-making processes, the ability to assign responsibility, and the effectiveness of control mechanisms remain of critical importance (Boin, van Eeten, 2013; Bovens, 2007). Deficiencies in these areas give rise to systemic risks, the source of which lies not in the technology itself but in the manner in which it is governed and managed.

The findings extend existing approaches in the literature, which have focused primarily on the technical aspects of cybersecurity or the regulatory frameworks governing AI systems. The analysis conducted indicates that the key challenge lies in the insufficient integration of the normative dimension with operational practice. In particular, a tension is evident between the efficiency of decision-making processes and the requirements of transparency and accountability, a tension that becomes increasingly pronounced in the context of digitalization (Pasquale, 2015; Crane, Matten, 2016).

This phenomenon is reflected in the observed tendency toward the "automation of accountability", whereby responsibility for decisions is increasingly shifted to algorithmic systems without a corresponding strengthening of institutional control mechanisms. As a consequence, situations may arise in which formal compliance with regulatory requirements does not translate into genuine transparency or the effective verifiability of decision-making processes (Bovens, 2007; Pasquale, 2015; Habibu, Obudra, 2025).

European Union regulations, including the AI Act and Regulation (EU) 2021/821, strengthen the normative and control dimensions of information management by introducing documentation requirements, risk assessment obligations, and oversight mechanisms governing the transfer of technologies (European Parliament and Council, 2024; European Parliament and Council, 2021). At the same time, they reveal a structural tension between the need to ensure security and the need to preserve innovation and operational efficiency. Excessive regulation may constrain the adaptive capacity of organizations, whereas insufficient regulation increases vulnerability to systemic risks.

From a public management perspective, the integration of information governance with risk management and quality management systems is of critical importance. The findings indicate that the effectiveness of control mechanisms depends not only on their formal implementation but also on the extent to which they are embedded in organizational processes and institutional culture (Power, 2007; Schein, 2010). This implies that information management ethics cannot be reduced to a matter of compliance alone; rather, it should be regarded as an integral component of organizational culture and management practice.

In this context, the proposed four-dimensional model may be interpreted as a tool that integrates three levels of analysis: normative, organizational, and systemic. Its significance lies in demonstrating the mechanism through which ethical standards influence the quality of decision-making processes and, consequently, the level of institutional resilience (Boin, van Eeten, 2013).

Accordingly, non-military security may be reinterpreted as the outcome of an organization's ability to manage information in a responsible, transparent, and governance-oriented manner. This perspective shifts the focus from reactive crisis management toward the proactive development of information systems that are resilient to disruptions and abuses (Rhodes, 1996; Floridi, 2013).

8. Conclusion

The theoretical considerations and qualitative analysis conducted in this study support the view that information management ethics may be regarded as a structural component of the non-military security of states and organizations. In the context of digital transformation, information has ceased to serve merely as a resource supporting decision-making processes and has become a strategic asset that determines institutional resilience and systemic stability.

The results of the comparative analysis indicate that the primary source of risk is not the level of technological advancement itself but rather the quality of information management. Regardless of the specific characteristics of the areas examined - including high-risk artificial intelligence systems used in public decision-making, dual-use technologies, and state information infrastructure - the transparency of decision-making processes, the ability to assign responsibility, and the effectiveness of control mechanisms are of fundamental importance. Deficiencies in these areas give rise to systemic risks, including decision-making errors, informational destabilization, and the erosion of trust in public institutions.

The analysis supports the argument that non-military security may be interpreted as being closely related to the quality of information governance. This perspective suggests a shift in focus from viewing threats primarily in technological terms toward the analysis of management processes that determine how information is used within public and organizational systems. From this standpoint, information management ethics may be understood as a mechanism that has the potential to mitigate systemic risk through the integration of normative, operational, and control dimensions.

The proposed four-dimensional model should be regarded as a theoretical framework that explains possible relationships between information governance and institutional resilience. The analysis suggests that the interaction of normative, procedural, control, and cultural dimensions may contribute to the development of more coherent information management

systems and may support resilience-building efforts. However, the effectiveness of these mechanisms has not been empirically verified within the scope of this study and therefore requires further investigation in real organizational and public-sector settings.

The findings also underscore the importance of linking formal regulations with organizational practice. The effectiveness of oversight and control mechanisms derives not solely from their normative foundations but also from their actual implementation within management processes and organizational culture. In this context, information management ethics should be regarded not merely as a component of compliance but as an integral element of management systems and resilience-building efforts.

The article contributes to management studies by conceptualizing non-military security as an outcome of the quality of information management and by identifying the mechanism through which ethical standards contribute to the stability of public and organizational systems. The proposed approach is application-oriented and may serve as a foundation for the design of information security policies and the development of governance systems in both public administration and the private sector.

Future research should focus on the empirical validation of the proposed model and on examining its application in public management practice, particularly in the context of implementing regulations related to artificial intelligence and cybersecurity.

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BATCH PRODUCTION: AN EXPLORATION OF THE SENSITIVITY WITHIN THE PRODUCTION PROCESS

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Purpose: In recent years, manufacturing companies have been facing an increasing number of disruptions to production systems, as well as broader effects. This paper discusses the impact of disruptions on the batch production process.
Design/methodology/approach: This research paper aims to explore methods for analyzing the production process's sensitivity to disruptions without disrupting system functioning. The focus of the research is on batch production, specifically rhythmic production. The following research methods were employed at each stage of the study: (1) Data collection stage – continuous observation and interviews with employees; (2) Research stage – simulation modeling and simulation experiments; (3) Results analysis stage – rhythmicity index analysis. The manufacturing process at a company that produces valves for the water and sewage industry was studied. A case study was conducted to investigate the process sensitivity to selected internal disruptions identified at the company. The research was performed using Tecnomatix Plant Simulation software. Experiments were conducted on four selected disruptions, including limited station throughput, low employee efficiency, high machine failure rate, and quality defects in delivered materials.
Findings: The conducted research has shown that the rhythmicity index can be used to assess a process's sensitivity to internal disturbances. It is worth noting that it is possible to examine both positive and negative rhythmicity index indices, allowing for the assessment of the impact (both positive and negative) of a given parameter on the analyzed process.
Research limitations/implications: The study investigated specific internal disruptions in batch production processes, focusing on a selected manufacturing process for devices used in the water and wastewater industry. The conclusions derived from this research can be applied to manufacturing companies across various sectors.
Practical implications: Simulation modeling enables the sensitivity of the production process to disruptions to be examined. The proposed rhythmicity index provides a detailed analysis of the impact of a given disturbance on the process, divided into positive and negative impact analysis. Research has demonstrated that the effects of a disruption differ when viewed from these two perspectives. This method of assessing the sensitivity of the production process is essential for effective decision-making.
Originality/value: A review of the literature indicates limited research on the analysis of internal disruptions affecting the production process. No studies have specifically addressed batch production in this context. One key advantage of this approach is the ability to assess the

sensitivity of production processes using the rhythmicity index. This offers significant convenience to manufacturing companies when deciding which disruptions are critical to the production process.
Keywords: batch production, simulation modeling, sensitivity, disruption, rhythmicity index.
Category of the paper: research paper.

1. Introduction

In today's rapidly changing markets and increasingly complex manufacturing environments, the ability to respond effectively to disruptions has become a matter of strategic importance. Disruptions are no longer viewed merely as undesirable incidents but as valuable sources of insight into system vulnerabilities and opportunities for improvement (Klumpp, 2017).

Manufacturing companies experience various disruptions that can be classified into two primary categories: internal disruptions, arising from factors within the organization, and external disruptions, related to the organization's environment (Wirkus, Maciagowski, 2011). External disruptions have been extensively studied in the literature, with a noticeable increase in analyses following the COVID-19 pandemic and the war in Ukraine. In contrast, internal disruptions have received significantly less attention. However, organizations have substantial influence over these internal factors through careful observation, research, and the implementation of appropriate measures. It is important to acknowledge that disruptions in the production process are inevitable and can arise from various aspects of process execution.

The study focused on batch production, characterized by a certain level of process repeatability (production order schedule, range of possible operations), which enables the prediction of disruptions and helps mitigate their impact. However, batch production also presents challenges, particularly the need to adapt to changes in product ranges and irregularities in material deliveries—such as variations in types, quantities, and delivery dates. Due to frequent disruptions during the production process, it is challenging to identify which are most critical to maintaining production continuity. Therefore, it is essential to correctly identify and classify these disruptions based on their expected impact and scale. This impact is often determined by the vulnerability of the process under study to disruptions (Burggräf, Dannapfel, Hahn, Schulz-Isenbeck, 2022) and related factors, including its sensitivity.

Manufacturing companies face the challenge of measuring how disruptions impact the stability of their processes. While various risk assessment and scenario methods can be applied, finding a universal indicator remains difficult. Due to the study's limitation to batch production, it was decided to investigate the use of a rhythmicity index. This index evaluates production stability by quantifying both positive and negative deviations from an established production standard.

A systematic analysis of disruptions enables a more effective and efficient response to challenges in production processes. This approach also enhances an organization's flexibility by adapting to the actual conditions of process performance. Furthermore, it should be one of the essential elements of a manufacturing company's strategy, integrating technical, organizational, and human factors towards building a culture of continuous improvement.

The purpose of the presented manuscript is to explore the possibility of analyzing the sensitivity of the production process to disruptions without disturbing the functioning of the system. Section 2 presents the results of literature research on batch production characteristics, process sensitivity characteristics, and the feasibility of simulation modeling. The research method is described in Section 3. Section 4 features a case study demonstrating the process sensitivity investigations using the rhythmicity index in a chosen manufacturing process for devices used in the water and wastewater industry. The discussion of the obtained research results is presented in Section 5. Section 6 summarizes the manuscript and outlines potential future research directions.

2. Literature review on the use of simulation modeling in the sensitivity analysis of manufacturing processes

Batch production is a type of production in which the number of products manufactured with a given machine setting is high (at least several dozen), and their diversity is low. There are several types of serial production: (1) non-repetitive production and (2) repetitive production (within a repetition period) – these periods may be the same or variable. In terms of production rhythmicity, the distinction between rhythmic and non-rhythmic production is used. The following section of the paper focuses on the characteristics of batch, repetitive production (Lis, 1982).

Batch (repetitive) production can be characterized in terms of six criteria: (1) tooling, (2) employee qualifications, (3) space planning, (4) materials, (5) planning, and (6) transportation. The tooling must ensure the unification of the operations performed, regardless of the employee's level of competence. The workstations are equipped with universal tools to a small extent, and the work is performed using specialized tools (often taken from the toolroom), made to order for the production of a given series of products. Employees involved in technological processes usually have average qualifications but are distinguished by their comprehensive knowledge of the operations they perform. Significantly higher qualifications are required for service personnel (toolroom/machine and equipment maintenance). Workstations are most often grouped into modular cell (multi-item) or production lines, where the assignment of operations changes rhythmically. The range of materials is adapted to the planned production tasks. Planning ensures the repeatability of operations at individual

workstations. Therefore, once the production cycle plan has been implemented, it is carried out in a repeatable manner, possibly incorporating adjustments due to delays in the work performed. Transport is carried out by using universal tools, but more often specialized tools dedicated to a given production process (Chambers, 2010).

The literature also refers to the layout of workstations used in batch production. Chambers distinguishes between functional and cellular layouts (Chambers, 2010). The functional layout focuses on the functions performed by the company's resources, grouping resources with similar functionality. This promotes better utilization of the potential of the accumulated machines. The material flow path is determined in accordance with technological requirements, with the material adapted to the capabilities of the operation. As a result, the material flow is complex and challenging to control. This system is characterized by high flexibility in product range, but the degree of infrastructure utilization is low. In a cellular system, the appropriate resources for operation are selected and grouped into a given cell. This system guarantees higher throughput and fewer errors. However, for the company, a larger number of resources is required, and any changes to the selected system will be costly (Chambers, 2010). The characteristics of the systems presented correspond to the previously described division into production lines and modular cells.

Defining the sensitivity of production systems to threats can be quite challenging. It is very often associated with system vulnerability analysis. To clarify this concept, it is useful to reference definitions of sensitivity provided by established figures in risk management and business continuity management. Sensitivity is considered a key element of vulnerability, as it helps determine a system's predisposition to specific events (Birkman, Cardona, 2013). Al-Khudhairy et al. define sensitivity as the degree to which a system is exposed to hazards. This exposure is one of three indicators of vulnerability, along with the degree of loss and impact caused by a hazard and the degree of resilience (Al-Khudhairy, Axhausen, 2012). According to Turner et al., vulnerability refers to the system-environment interface. It indicates that sensitivity is the degree to which a system maintains its ability in response to internal and external environmental factors. This implies that sensitivity influences the extent to which a system can adapt to changing conditions (Turner, 2003). A similar approach is presented by Adger, who points out that sensitivity to hazards defines a system's vulnerability, understood as the level of exposure to undesirable events (Adger, 2006). McEntire offers a more detailed definition, describing sensitivity as the degree of risk—specifically, the extent to which a disruption can negatively affect the object or system under study (McEntire, 2011). The literature on the subject also introduces the concept of production process resilience, defined as a system’s ability to absorb disruptions and reorganize in response to changes while maintaining its function, structure, identity, and responsiveness (IPCC, 2012). Resilience is understood as the potential of a specific system configuration to maintain its structure and functionality during threats, as well as its ability to reorganize and adapt (Lebel et al., 2006). The definitions provided indicate that sensitivity is a key aspect of a process's vulnerability to

disturbances, making it a more specific concept. Both sensitivity and vulnerability, of which sensitivity is a part, examine how a given disruption affects the process and assess how much the process deviates from its expected course. In contrast, resilience focuses on a company's ability to implement actions that enable the process to respond effectively to disruptions and quickly return to normal operation.

The literature review revealed limited research on the sensitivity of production processes to disruptions through simulation modelling. The research was conducted by searching the Scopus database for publications matching the specified search criteria. In the following stages of the study, the range of keywords entered became increasingly detailed to refine the analysis results. The results obtained in the subsequent steps of the study are presented in Table 1.

Table 1.
Results of literature review

Used keywords	Res. #1	Res. #2	Res. #3	Res. #4	Res. #5	Res. #6	Res. #7
Production / Manufacturing	⊕						
Production companies / Production enterprises / Manufacturing companies / Manufacturing enterprises /	⊕	⊕	⊕	⊕	⊕	⊕	⊕
Production process / Manufacturing process		⊕	⊕	⊕	⊕	⊕	⊕
Sensitivity	⊕						
Sensitivity research / sensitivity study / sensitivity analysis		⊕	⊕	⊕	⊕	⊕	⊕
Simulation modeling / simulation modelling			⊕		⊕		
Batch production				⊕	⊕		
Production process sensitivity/ Manufacturing process sensitivity						⊕	
Process sensitivity							⊕
Results	2116	173	8	2	0	0	0

Source: own study.

The results indicate that research on the sensitivity of production processes is reported in scientific publications. However, a closer analysis of the manuscript revealed that the study focuses on the chemical properties of the substances used in the process or on the strength of the materials. On the other hand, narrowing the analysis to keywords such as mass production or simulation modeling significantly reduced the number of publications. However, the few identified publications highlight the growing opportunities to study the sensitivity or vulnerability of production processes to disruptions.

Sensitivity analysis plays a vital role in assessing the robustness of production systems and understanding how variations in key parameters influence operational performance. Studies have demonstrated that even minor fluctuations in factors such as processing times, machine availability, or capacity constraints can significantly affect scheduling efficiency and production outcomes (Yang, 2012; Dhand, Singla, 2016). Research in this field has employed both analytical and simulation-based approaches to evaluate the stability of production schedules and optimization models under uncertain conditions. Analytical methods, including the dual-phase simplex approach, enable determination of parameter ranges within which an optimal solution remains valid, while simulation models allow exploration of nonlinear relationships and interdependencies in complex manufacturing environments (Grznár et al., 2024). In recent years, the scope of sensitivity analysis in manufacturing has expanded beyond traditional scheduling problems to include evaluating system adaptability and structural flexibility. Burggräf, Dannapfel, Hahn and Schulz-Isenbeck (2022) applied local sensitivity analysis to assess how the definition and weighting of layout changeability metrics influence their reliability and interpretability in automated production evaluation. Similarly, Grznár et al. (2024) demonstrated that global and variance-based sensitivity methods applied to simulation models enhance understanding of system behavior under uncertainty and support the development of more resilient and adaptive production systems. Collectively, these studies highlight the strategic importance of sensitivity analysis as a foundation for process optimization, informed decision-making, and continuous improvement in modern manufacturing environments.

3. Methodology

A literature review found a lack of studies on the use of simulation modeling to analyze the sensitivity of production processes (in batch production) to disruptions. Accordingly, this paper applied the presented approach, using an exploratory case study as the research method. This method is used to study little-known and poorly defined phenomena that are in the early stages of recognition (Ellram, 1996). The research procedure used is presented in Figure 1.

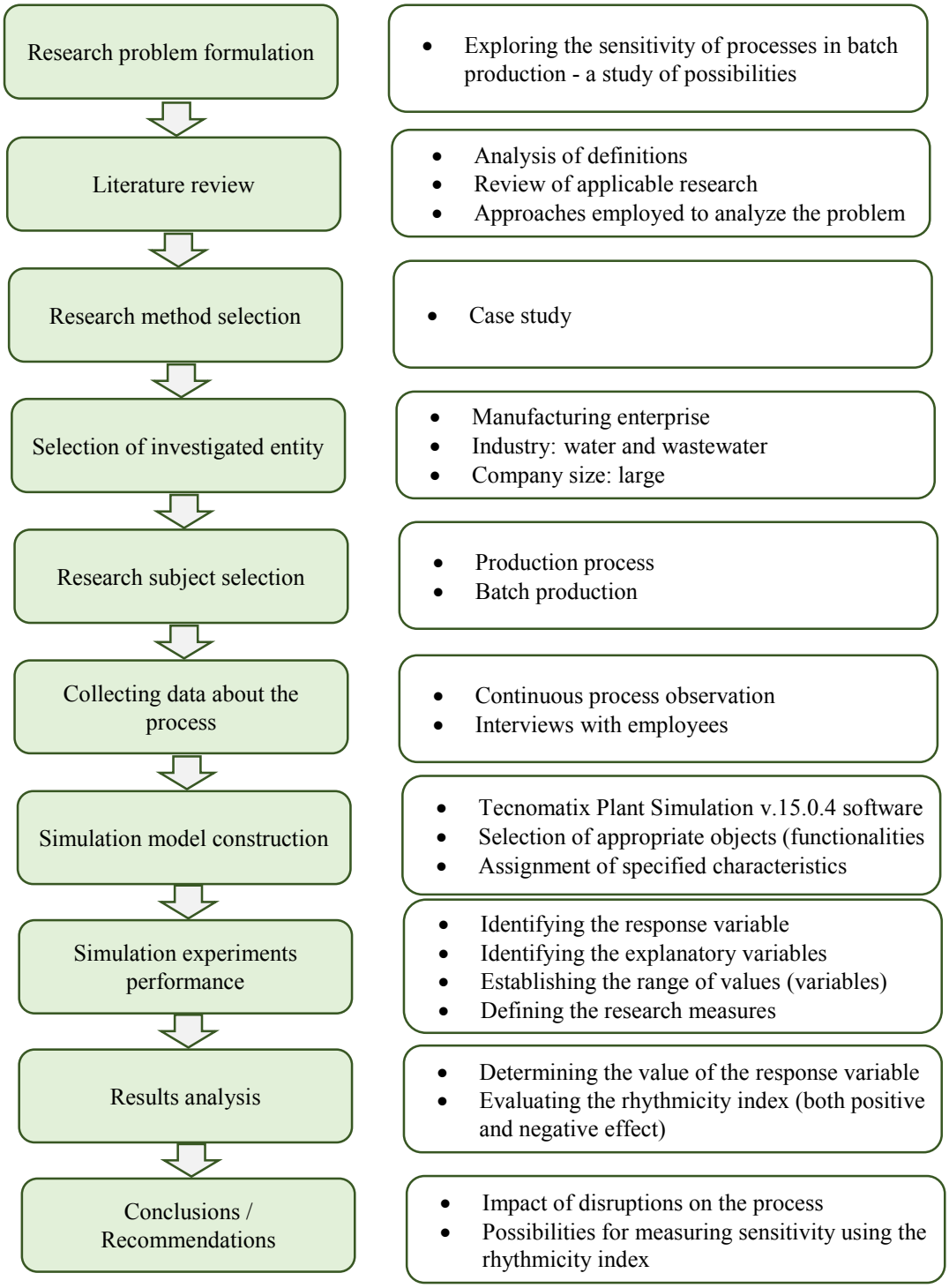

Figure 1. Research methodology.

Source: own study.

The initial stages of the procedure, namely the formulation of the research problem and the literature review, are presented in the “Literature review” section. The “Methodology” section presents the research method employed and describes its selection. The “Results” section characterizes the production process under analysis, constructs a simulation model, and then conducts simulation experiments. The results analysis and recommendations for the studied process are presented in the “Discussion” section.

4. Results

The subject under study was the production process conducted in the selected manufacturing company in the water and wastewater industry. The study was carried out in the form of a case study.

The research problem addressed in the study concerned the feasibility of investigating the sensitivity of manufacturing processes through simulation modeling. According to the literature review, such a study has been conducted only in a limited manner. Attempts to address the topic of process vulnerability to disruptions have been made in (Smagowicz, 2024). This study focuses on batch production, which is characterized by unique data characteristics, and examines sensitivity analysis as a measure of vulnerability.

Section 2 defines sensitivity as the extent to which a disturbance affects the object under study. In manufacturing companies, it's important to differentiate between external disruptions—those caused by factors outside the organization—and internal disruptions, which originate from within the organization. This research examines specific internal disruptions experienced by manufacturing enterprises.

Characteristic of the process selected for study

The study focused on a specific stage in valve production for the water and wastewater industry. This stage consists of three parts: washing semi-finished products (M), verifying their dimensions (W), and conducting leak tests (T). Detailed characteristics of the selected process, the subject of the study, are presented in Table 2.

Table 2.
Characteristics of the process selected for study

Characteristics	Description
Type of production	Batch (repetitive) production.
Form of production organization	Line production (rhythmic).
Type of equipment	Universal tooling – to a small extent; specialized tooling – to a large extent.
Employee qualifications	Average level of employee competence; some employees specialized in specific tasks.
Transport	Transport performed manually or using dedicated equipment.
Type of operations performed	Operations performed automatically and manually to maximize the number of disruptions possible for research.
Capacity constraints	The bottleneck of the process at the 'Housing cleaning' station by using an advanced BottleneckAnalyzer tool.
Working hours	The production process is performed in two shifts. Each shift lasts 8 hours. There are two breaks of 5 minutes each and one break of 15 minutes.
Number of employees	There are 2 employees in the examined area who move freely around workstations.
Standardization of processes within the company	The production process under review has been implemented at the company for 5 years.

Source: own study.

The process is composed of 24 workstations – 21 workstations require manual operation by an employee; the remaining 3 are operated in automatic mode. The production parameters for the individual workstations are shown in Table 3.

Table 3.
Characteristics of the implemented process

Name	Operation	Average operation time [s]	Availability [%]	MTTR [s]	Operating mode
M1	Loading of housings	270	90	60	Manual
M2	Layout check	30	90	60	Manual
M3	Basket insertion	15	90	60	Manual
M4	Basket retrieval	15	90	60	Manual
M5	Washing and rinsing	900	90	60	Manual
M6	Drying	300	90	60	Manual
M7	Additional drying	-	-	-	Automatic
M8	Receiving housings from conveyor	15	90	60	Manual
M9	Housing cleaning	90	86	90	Manual
M10	Housing positioning	30	86	60	Manual
M11	Preliminary operation WP1	45	86	60	Manual
M12	Measurement check	15	86	60	Manual
M13	Housing unloading	15	86	60	Manual
M14	Report generation	-	-	-	Automatic
M15	Setting aside defective housings	8	86	60	Manual
M16	Passing correct housings	8	86	60	Manual
M17	Placement in holder	30	80	120	Manual
M18	Device sealing	90	80	120	Manual
M19	Table positioning and rotation	30	80	120	Manual
M20	Operation T1	45	80	120	Manual

Cont. table 3.

M21	Transition to stage T1	-	-	-	Automatic
M22	Transport to assembly	15	80	120	Manual
M23	Transport of parts	15	80	120	Manual
M24	Transport of defective parts	15	80	120	Manual

Source: own study.

The analysis focused on a selected production area, where significant productivity decreases and frequent disruptions were observed, resulting from irregularities in component cleaning quality, metrological measurements, and housing strength tests.

Simulation model development

The simulation model was built using Tecnomatix Plant Simulation (ver. 15.0.4). The model is composed of 38 objects, assigned to libraries such as Material Flow, Resources, Tools, and User Interface. The used objects represent the operations performed on each workstation. The model was validated. The model results confirmed the correctness of the constructed model. The visualization of the production process in the simulation model is shown in Figure 2.

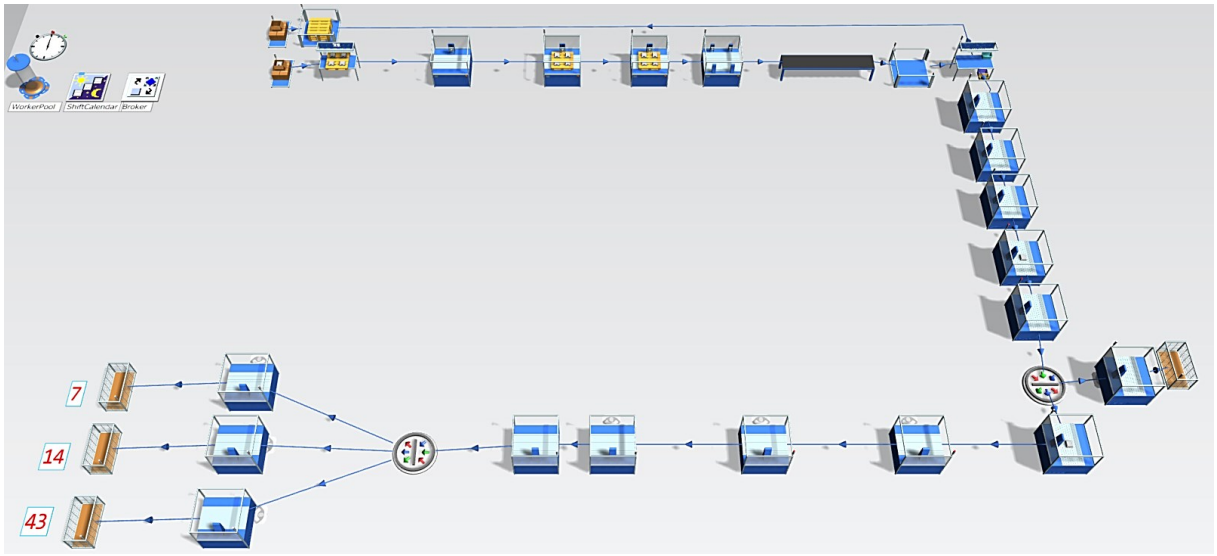

Figure 2. Visualization of the simulation model constructed.

Source: own study.

The simulation was carried out for 1 working day, and the result was 64 manufactured products – 43 products were approved for correct manufacturing, 7 products were specified as spare parts, and 4 products were identified as defective. To conduct further research on the impact of disruptions on process execution, a process bottleneck was identified using the advanced BottleneckAnalyzer tool integrated into Tecnomatix Plant Simulation. The results indicated a bottleneck at station M9 - these findings were confirmed by the station's workload and participant observation conducted in the production area under study. Long execution times at workstations M5 and M6 suggest a possible bottleneck. However, work at these stations

involves several semi-finished products simultaneously, indicating that station M9 is the limiting factor in the process's throughput.

Disruptions identification

A production disruption refers to unintended changes in the properties of production system objects, leading to undesirable deviations from the planned sequence. The study divides production disruptions according to the area in which they are observed. Table 4 presents the main production disruptions identified for batch production. This production is performed in a line production (rhythmic) form.

Table 4.
List of disruptions occurring in batch production

Area of occurrence	Type of disruption
Supply	• Delays in workstation deliveries • Quality defects in delivered materials/semi-finished products • Damage to materials/semi-finished products during transport • Delivery of incorrect materials/semi-finished products • Lack of availability of key components • Incorrect order specifications • Inappropriate safety stock management
Production	• Unstable operation of machines/equipment, leading to increasing operation times • Problems with maintaining machine operating parameters (equipment calibration) • Incorrect execution of operations • High frequency of changeovers • High machine failure rate • Lack/Damage of tooling • Limited throughput of workstations • Increase the cost of resources used • Inappropriate planning of the sequence of operations • Low quality of technical supervision • Lack of standardisation of work activities
Employees	• Insufficient number of employees • Low employee efficiency • Overloading of employees with tasks • Low/inadequate employee qualifications • Conflicts in interpersonal relations • High staff turnover • Lack of motivation/ commitment • Failure to comply with health and safety rules
Storage	• Lack of permanent storage areas for materials/semi-finished products • Lack of local warehouses at workstations • Frequent movement of materials/semi-finished products around storage locations • Excessive production inventory • Damage to materials/semi-finished products during storage • Incorrect labelling or marking of batches • Inappropriate storage conditions (e.g. temperature, humidity)
Transport	• Faulty transport equipment • Long transport routes around workstations • Inappropriate organisation of material flow • Lack of internal transport resources • Interruptions in the material flow (congestion, downtime)

Cont. table 4.

Supporting processes	• Incorrect control of tasks being performed • Variability of production plans • Incorrect production order • Incorrect environmental conditions • Incorrect batch marking • Incorrect production planning/scheduling • Changes in norms/standards/regulations • Lack of up-to-date technical instructions • Inconsistency between production planning and implementation

Source: own study based on Gaschi-Uciecha, 2015, pp. 136-139.

The identified disruptions are closely related to the nature of batch production, which, on the one hand, has the characteristics of mass production with an organized and repeatable (to a certain extent) flow. Therefore, the selected disruptions significantly impact the implementation of the production plan. For example, a machine failure causes downtime because it is not possible to quickly transfer the order to another workstation, as would be the case in unit production or in a specific technological cell, with redirection of operations to another available machine.

On the other hand, the flow is not constant, and the production of a given batch lasts for a limited time, after which the range of manufactured components changes. This means, among other things, that employees must have the appropriate skills to adapt to changes in the range of manufactured products and that it is difficult to quickly replace one employee with another.

Conducting the study

The evaluation of the course of batch and repetitive production can be based on a range of metrics. The choice of metric depends on the objectives set during the design or investigation of the system and on the feasibility of performing appropriate measurements or calculations. Natural metrics are always of fundamental significance, although their direct use is difficult due to the diversity of the subject matter. In terms of the research, it is crucial to determine the sensitivity of the production process to disturbances, i.e., the degree to which a given factor influences the planned course of the process. The analysis will be based on the measurement of the production rhythmicity index. Production rhythmicity can be measured in two ways: (1) by comparing actual production performance with plan assumptions, and (2) by comparing actual production performance records in the analyzed time intervals. In the further part of the study, it was decided to measure the rhythmicity index, which allows for the examination of deviations in production volume from the planned volume, thereby enabling the analysis of the stability, consistency, and regularity of the production plan's implementation. The rhythmicity index K accounts for both positive and negative deviations from the planned production plan. It is defined as the sum of the positive (K_d) and negative (K_u) deviation indices:

$$K = K_d + K_u \quad (1)$$

The partial factors are calculated according to the following formulae:

$$K_d = \frac{\sum P_{fi}^r}{\sum P_{pi}^r} - 1, K_u = 1 - \frac{\sum P_{fi}^r}{\sum P_{pi}^r} \quad (2)$$

where:

P_{fi}^r – actual production volume in the analysed time interval,

P_{pi}^r– planned production volume in the same interval.

The summation in the above formulas includes, respectively:

- in the case of K_d – intervals in which positive deviations occurred (production exceeded the plan),
- in the case of K_u – intervals in which negative deviations occurred (production was lower than planned).

A K value > 0 indicates the occurrence of variances and deviations in the implementation of the analyzed production process.

Four key process disruptions were selected for further analysis in the study. These include: (1) limited throughput of the M9 station identified as a process bottleneck, (2) low employee efficiency, (3) high failure rate of the M9 workstation, and (4) the occurrence of quality defects in the delivered materials, which delays the start of the process. For each disruption, the main characteristics of the study were determined, including the initial value of the explanatory variable, the range of change in the explanatory variable, and the measured values (the response variable). It should be noted that the process sensitivity study took into account changes that had negative and positive effects on the value of the response variable – the number of products manufactured. A detailed summary of the parameters is presented in Table 5.

Table 5

List of characteristics of disruptions subject to examination

Disruption	Characteristic	Range of examined values	Measured value
Limited throughput of M9 workstation M9	Operation time – 90 seconds	Range: 75-110 [s] (12 [s] increment)	Number of manufactured products
Low employee efficiency	Employee efficiency – 80%	Range: 60-100% (4 [%] increment)	Number of manufactured products
High failure rate of the M9 workstation	Availability level – 86%	Range: 71-100% (3 [%] increment)	Number of manufactured products
Quality defects in delivered materials	Operation time – 270 seconds	Range: 210-330 [s] (12 [s] increment)	Number of manufactured products

Source: own study.

Performance of simulation experiments and analysis of results

The results obtained in the experiments are presented in Table 6. For each disruption examined, the explanatory variable and response variable values are presented. It should be noted that 40 observations were made in each experiment (to obtain reliable results for the number of manufactured products, taking into account the assumed percentage availability of machines and the introduced failure rates).

Tabel 6.
Summary of experimental results

No.	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Exp. 6	Exp. 7	Exp. 8	Exp. 9	Exp. 10	Exp. 11
Disruption #1											
Explanatory variable	110	106	102	98	94	90	86	82	78	74	70
Response variable	61	61	63	63	64	64	65	67	68	68	70
Disruption #2											
Explanatory variable	60	64	68	72	76	80	84	88	92	96	100
Response variable	56	58	62	63	64	64	67	67	69	71	72
Disruption #3											
Explanatory variable	71	74	77	80	83	86	89	92	95	98	100
Response variable	61	62	62	63	63	64	65	65	66	68	68
Disruption #4											
Explanatory variable	330	318	306	294	282	270	258	246	234	222	210
Response variable	60	61	62	62	64	64	65	66	66	67	69

Source: own study.

Experiment 6 outlines the values of both the explanatory and response variables in their initial state, reflecting the current production process. The other experiments show results consistent with the values assumed for the individual characteristics listed in Table 5. Figure 3 illustrates these results by graphing the range of values that the response variable can take.

The results indicate that the widest range of values for the response variable occurs in disruption #2, which describes employee efficiency. Furthermore, in the study of selected disruptions, the impact of changes in the explanatory variable differs between positive and negative changes. The predominance of a positive effect is evident in three of the four disruptions studied, with the most significant difference observed in disruption #1, which characterizes the M9 workstation's throughput.

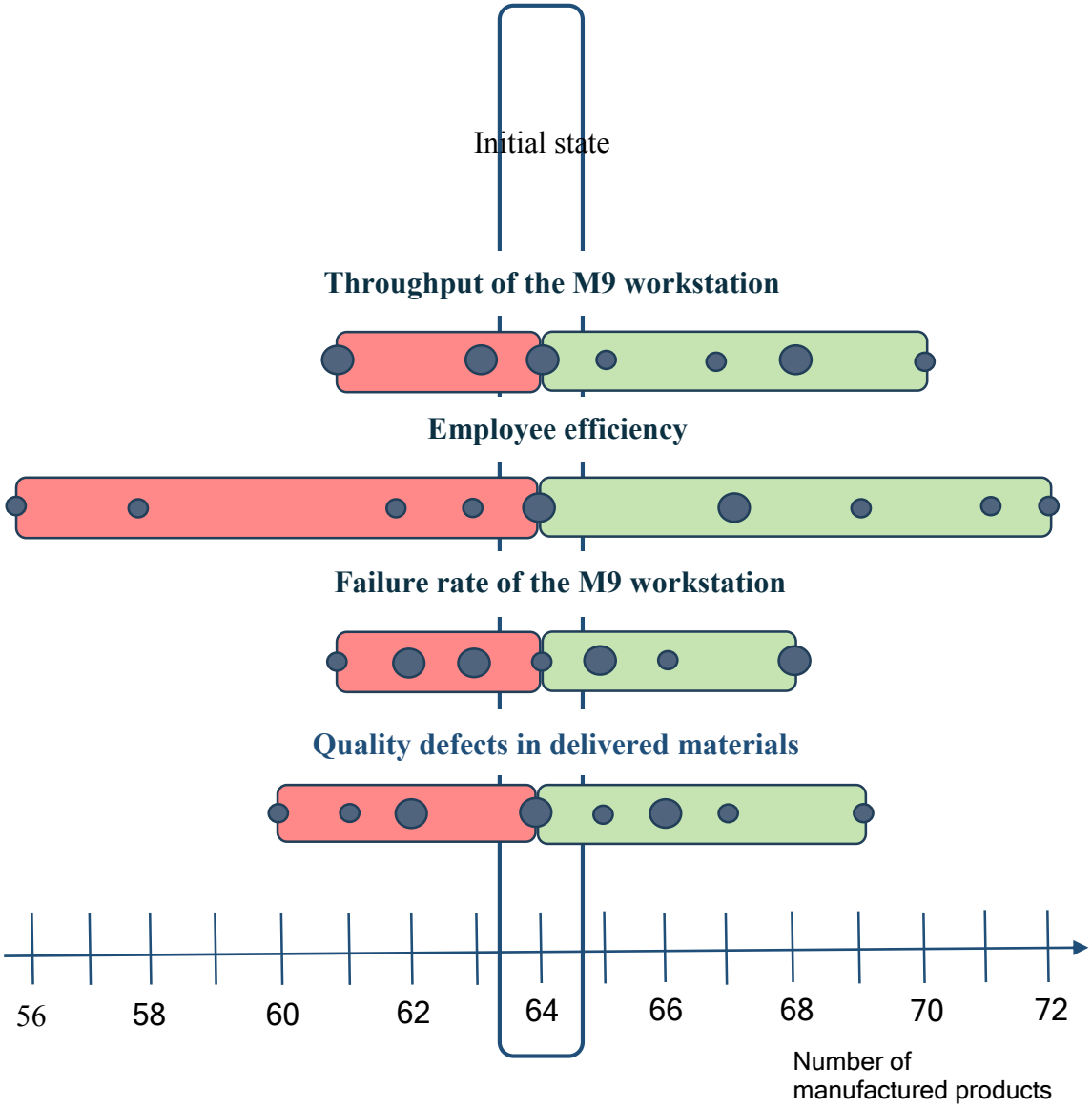

Figure 3. Results obtained in the experiments.

Source: own study.

Based on the results, a rhythmicity index was calculated for each disruption using formula (1). The measurements of rhythmicity show both positive and negative deviations for individual disruptions. The overall value of the rhythmicity index, which is the sum of these deviations, is summarized in Table 7.

Tabel 7.

Results of the rhythmicity index

	Disruption #1	Disruption #2	Disruption #3	Disruption #4
Rhythmicity index	0,08125	0,134375	0,065625	0,075

Source: own study.

The rhythmicity index values obtained for individual disruptions were above 0. This means that each disruption affects the implementation of the examined process. The highest index value was obtained for disruption #2, related to employee productivity. On the other hand, disruption #3, the failure rate of workstation M9, had the least influence on the process. These results confirm the conclusions drawn from the experiments.

5. Discussion

As part of the study, an analysis of four selected disruptions classified as disruptions occurring in batch production was carried out. The results of the experiments and the determined rhythmicity index indicate that the most significant impact on the production process is due to changes associated with disturbance #2, which concerns employee efficiency. This situation may arise when an employee is unsure how to execute tasks correctly during a change in the product assortment, which may require proper machine retooling or workstation preparation. Additionally, consistently performing a specific set of activities for a given batch of products can lead to fatigue from the monotony of the work. While employees may not have specialized knowledge, they possess a wide range of competencies related to the operations they perform. This scenario can increase stress and require more careful consideration when carrying out tasks, potentially extending the duration of operations to avoid mistakes. It should be noted that achieving the learning curve effect is challenging in batch production. The study of the process's sensitivity to the analyzed disruption was based on findings from participant observation. Additionally, employees' stress levels and job monotony were assessed on a broad scale. As a result, it is challenging to draw general conclusions from the findings, which represents a limitation of the study.

The results indicate that the response variable exhibits a similar range of positive and negative changes as the explanatory variable varies. However, the results indicate that the negative rhythmicity index takes higher values than the positive one.

A further disruption impacting the production process (to a lesser extent) was the throughput of workstation M9. This workstation was identified as a bottleneck in the process, which is why changes to the operational parameters affect the production result. An increase or decrease in throughput at the bottleneck directly impacts the throughput of the entire production process under study. Therefore, from a process-flow perspective, it is crucial to keep the M9 workstation continuously engaged in production tasks, as even a momentary downtime will reduce productivity. The experiments show that the range of changes in the response variable is smaller as the explanatory variable increases and larger as it decreases. The results were also confirmed during the study of the rhythmicity index: the negative rhythmicity index takes smaller values than the positive one.

Quality defects in the delivered materials were another disruption affecting the production process. The materials are strictly assigned to a given production order, leading to discrepancies in the quality, quantity, or type of materials ordered. At the same time, control of the delivered components may take longer due to changes in the product range, so the employee may not remember the specific delivery conditions. The results of the experiments indicate that the range of changes in the response variable is greater when the explanatory variable decreases. This phenomenon is also confirmed by the results of the rhythmicity index – the positive rhythmicity index is higher than the negative one.

The least impact on the process is caused by phenomena related to disruption #3, characterized by the failure rate of machine M9. In batch production, due to specialized tools and tooling changes depending on the products manufactured, more frequent failures may occur at the workstation. Equipment failure may also be caused by a lack of specialist knowledge of tool use, which increases the likelihood of damage or improper operation. The experiments indicate that the range of changes in the response variable is greater when the explanatory variable increases and smaller when it decreases. The results were also confirmed during analysis of the rhythmicity index - the positive rhythmicity index takes higher values than the negative one.

The rhythmicity index examined in the experiments proved essential for analyzing disruptions in production processes. It allows evaluation of the impact of unwanted actions and identification of which disruptions are significant for ensuring production continuity and achieving planned results. It is crucial to examine this factor when the range of parameters changes across the experiments is similar. The values of the positive and negative rhythmicity index enabled the determination of which changes (positive/negative) have a greater impact on the process being carried out.

Conclusions

The presented research examined the sensitivity of the production process as one element of studying the system's vulnerability to disruptions. The use of simulation modeling enabled the digital representation of the production area under study and the conduct of experiments without disrupting system performance. Additionally, it enables simultaneous answers to various questions, such as the type or extent of a given disruption's impact. In future research, the feasibility of verifying solutions that minimize the impact of disruptions on the system under study will be investigated.

The rhythmicity index utilized in this research is an important tool for assessing the effects of individual disruptions. A key advantage of this factor is its capability to analyze impacts separately, distinguishing between positive and negative deviations. This allows verification of

how each change affects the process and confirms that the impacts are not equal. By systematically monitoring the rhythmicity index, we can enhance the stability of production processes, ultimately increasing productivity. The objective of this paper was to verify the impact of specific disruptions on the production process under study. As part of future research, the authors plan to adopt a broader approach to analyzing the combined effects of multiple disruptions simultaneously to determine which concurrent disruptions reinforce one another and exacerbate the negative impact on the process. This would also enable verification of a potential cascade effect in the analyzed process, allowing for the implementation of appropriate preventive measures in the future.

The approach presented in this paper is constructive for decision-making in manufacturing companies and can be adapted by companies across any industry.

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MANAGING SOCIO-ECONOMIC DEVELOPMENT IN THE EUROPEAN UNION – A COMPARATIVE ANALYSIS OF MEMBER STATES (2010-2025)

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Purpose: The aim of the article is to evaluate the level of socio-economic development of European Union Member States between 2010 and 2025 and to identify key factors influencing development management.
Design/methodology/approach: The study is based on secondary data analysis using Eurostat and UNDP databases, supported by comparative and descriptive analysis as well as an examination of relationships between selected socio-economic indicators.
Findings: The results indicate a general improvement in socio-economic development across EU Member States, reflected in higher GDP per capita and HDI values, lower unemployment rates, and a positive relationship between economic and social development.
Research limitations/implications: The study is limited by its reliance on secondary data and a selected set of macroeconomic and social indicators, which do not fully capture the complexity of socio-economic development.
Practical implications: The findings may support policymakers and public institutions in designing and evaluating development strategies aimed at strengthening socio-economic cohesion and sustainable growth.
Social implications: The results highlight the importance of investments in human capital, education, and social well-being as key factors contributing to improved quality of life and long-term development.
Originality/value: The originality of the article lies in its comprehensive comparative assessment of socio-economic development across EU Member States over a fifteen-year period from a development management perspective.
Keywords: socio-economic development, European Union, GDP per capita, Human Development Index, public debt, unemployment, development management.
Category of the paper: research paper.

1. Introduction

Socio-economic development constitutes one of the key objectives of public policy implemented both at the national and European Union levels. Contemporary development management requires balancing economic growth with social progress, labour market development, public finance stability and improvements in citizens' quality of life. In recent years, increasing attention has been paid to the effectiveness of development management in European Union Member States, particularly in the context of economic crises, demographic changes, digital transformation and sustainable development challenges. Therefore, assessing the level of socio-economic development and identifying factors influencing development disparities among Member States has become an important research issue.

The aim of the article is to evaluate the level of socio-economic development of European Union Member States between 2010 and 2025 and to identify key factors influencing development management. The added value of the study lies in the comprehensive comparative assessment of socio-economic development across European Union Member States using selected economic and social indicators, including GDP per capita, public debt, unemployment rate and HDI.

The structure of the article has been subordinated to the achievement of the adopted research goal. The first part presents the theoretical foundations of socio-economic development and development management. Next, the methodological assumptions and analytical methods are discussed. The subsequent section presents the research results, followed by a discussion and conclusions concerning socio-economic development in the European Union.

Despite numerous studies on socio-economic development and the factors determining economic growth, there is still a lack of comprehensive comparative analyses covering all European Union Member States over a long-term time horizon. Such studies should simultaneously consider both economic and social indicators from the perspective of development management. Existing research has primarily focused on selected countries, regions, or individual aspects of development. The identified research gap provided the basis for undertaking the present study. Its added value lies in a comprehensive assessment of changes in the level of socio-economic development across European Union Member States between 2010 and 2025, as well as in the identification of relationships between selected economic and social indicators from a development management perspective.

The literature review indicates that previous studies have primarily focused on identifying the determinants of socio-economic development. These include the quality of institutions and entrepreneurship (Leitão, Capucho, 2021), regional conditions (Garina et al., 2019), human capital and education (Rahman, Hossain, 2025; Karpenko, 2025; Ali et al., 2025), as well as environmental issues and sustainable development (Madni et al., 2022; Medeu et al., 2025). The literature also emphasizes the role of digital transformation (Iryna et al., 2022),

the European Green Deal (Nagaj et al., 2024), and challenges related to development management in European Union Member States (Radchenko et al., 2024). At the same time, according to the literature review conducted, no studies were identified that provide a comprehensive comparative analysis of all European Union Member States over the period 2010-2025 while simultaneously considering both economic and social indicators from a development management perspective. This identified research gap provides the rationale for undertaking the present study and highlights its potential contribution to the advancement of knowledge on socio-economic development management within the European Union.

2. Literature Review

2.1. Theoretical determinants of the socio-economic development of countries

Each country, undergoing socio-economic development, also undergoes a complex and multidimensional process. It includes the transformations that are taking place in both the economic and social spheres. According to the modern approach to this issue, it can be assumed that development should not be identified only with economic growth. Instead, it should also mean improving the quality of life of society, access to education, health care, increasing the level of employment and creating conditions conducive to the development of human capital. In the scientific literature, it can be emphasized that the pace and direction of development are influenced by many interrelated economic, institutional and social factors. Leitão and Capucho (2021) point to the importance of the quality of institutions and entrepreneurship as factors supporting the development of countries. In turn, Garina and co-authors (2019) draw attention to the role of territorial and regional conditions in shaping development processes. The quality of scientific and research activities is also of great importance. It affects the economy's ability to create innovations, transfer knowledge and build competitive advantages (Didenko et al., 2022). Thus, as a result, socio-economic development is now seen as the result of the interaction of many interdependent determinants. These conditions shape the development potential of countries.

Among the most important determinants of socio-economic development, the level of education, technological development and the quality of human capital are increasingly mentioned. Rahman and Hossain (2025) are of the opinion that the implementation of modern technologies and investment in education significantly increase the productivity of the economy. They will also contribute to the growth of social welfare. A similar position is presented by Karpenko (2025) and Ali, Khan and Ali (2025). They point to the importance of education. They treat it as a factor that significantly increases social mobility. It also reduces inequalities and supports long-term economic growth. In turn, Bazaluk et al. (2025) show that

stable economic growth depends on the efficient use of resources, properly conducted economic policies and the ability of the state to support investments. In addition, health and social factors are increasingly important. According to research by Yeboah, Omonaiye, and Yaya (2025), the rate of economic growth affects the health level of society. In turn, according to the findings of Atusingwize, Deane and Musoke (2025), the importance of social determinants of health for the quality of life of residents is increasing. Similar relationships are indicated by Kapatsa and co-authors (2025) and Yermukhanova and co-authors (2025). They highlight the impact of socio-economic factors on public health. They also point to the development possibilities of societies.

Contemporary concepts of socio-economic development increasingly take into account the environmental aspect. Emphasis is also placed on the need to implement the assumptions of sustainable development. Madni, Anwar and Ahmad (2022) indicate that the level of socio-economic development affects the environmental performance of developing countries. In turn, Zeb, Shuhai and Ullah (2025) and Magazzino, Gattone and Madaleno (2025) believe that socio-economic factors play a large role in shaping the level of ecological footprint and the quality of the natural environment. A similar research stream includes the analyses of Cai and co-authors (2025), which indicate the impact of socio-economic factors on the level of carbon dioxide emissions, and the research of Dyanty and co-authors (2025), which emphasizes the importance of the adaptive capacity of societies to climate change. Maintaining a balance between economic growth and environmental protection also remains a significant challenge. This accent is highlighted by Kilgus and Shrum (2026). In addition, Najia, Taher and Elkader (2025) point to the importance of socio-cultural factors for the sustainability of developmental processes. Mbanefo and co-authors (2026), on the other hand, argue that effective public policy is needed to create conditions conducive to socio-economic development. This means that the modern development of states is the result of the impact of economic, social, institutional, technological, health and environmental factors, which together determine the level of prosperity and competitiveness of economies.

2.2. Contemporary challenges of socio-economic development management in the European Union

In order for EU countries to develop harmoniously, it is necessary to manage socio-economic development accordingly. This task is currently one of the most important areas of activity of public institutions that are responsible for shaping development policy. Today's Member States operate in conditions that are characterised by high complexity of economic and social processes. And this requires an integrated approach to development management. One of the main challenges remains reducing development inequalities between countries and regions. To achieve this, it is necessary to maintain the high competitiveness of the European economy at the same time (Wilczyńska et al., 2025). As Radchenko and co-authors point out (2024), effective management of regional development requires adapting

public policies to the specifics of individual areas. It is also necessary to take into account their social and economic potential. At the same time, the need to balance economic and environmental objectives is becoming increasingly important. These determinants can be considered the foundation of contemporary development strategies (Medeu et al., 2025; Voronina et al., 2024). Institutional capacity building, which supports the achievement of common European goals and effective international cooperation, also plays an important role in this process (Sudar et al., 2024).

The ongoing digital transformation remains a significant challenge for managing socio-economic development. Hence, there is a need to adapt management processes to the requirements of the knowledge-based economy. The development of digital technologies affects the way public administration, businesses and society function. It creates new opportunities. However, at the same time, it generates new risks (Iryna et al., 2022). Particular importance is attached to the development of smart infrastructure and the use of the smart city concept. These concepts support the effective management of urban space and public services (Yermachenko et al., 2023; Kaššaj, Peráček, 2024). With the development of digitization, new challenges are constantly arising. They are related to data protection, algorithmic management and ensuring appropriate standards of work in the digital environment (Aloisi, 2024). In addition, the experience of crises such as the COVID-19 pandemic has revealed the need to increase the resilience of public institutions. It is necessary to shape the capacity of countries to respond to global crises (Quaglia, Verdun, 2023).

Another area of challenge is the energy and ecological transition processes, which are being implemented as part of the European Green Deal. These include the need to reduce greenhouse gas emissions, develop a low-carbon economy, and increase the efficiency of natural resource use (Nagaj et al., 2024; Popescu et al., 2022). Agricultural land development is an important element, which is in line with the assumptions of the European Union's environmental policy (Fayet et al., 2022). The development of the circular economy is also becoming increasingly important. It will include modern waste management systems and rational use of raw materials (Agovino et al., 2024; Rebehy et al., 2023; John, Das, 2024).

The importance of these activities is confirmed by the research of Velis and co-authors (2023). They indicate a close relationship between the level of socio-economic development and the effectiveness of waste management systems. Contemporary challenges also include the need to ensure economic security and responsible management of natural resources (Song et al., 2023), effective management of water resources under climate change (Rossi, Peres, 2023), the development of solutions enabling the safe reuse of water resources (Radini et al., 2023), and the implementation of new regulations related to sustainability reporting of enterprises and institutions public (Odobaša, Marošević, 2023). Therefore, it can be said that modern management of socio-economic development requires a systemic approach. It should integrate economic, social, technological and environmental objectives.

3. Methods

The aim of the article is to evaluate the level of socio-economic development of European Union Member States between 2010 and 2025 and to identify key factors influencing development management. The focus was on following the analysis of changes taking place in the area of economic growth, the situation of public finances, the labour market and social development. An attempt was made to determine the extent to which selected economic and social indicators can be tools supporting development management processes at the national and supranational level. The following research questions were subordinated to the implementation of the research objective:

P1. How did the level of gross domestic product per capita in the Member States of the European Union change between 2010 and 2025?

P2. What changes have occurred in the level of public debt and the ratio of public debt to GDP in the analysed countries?

P3. What was the level of social development measured by the HDI index in the Member States of the European Union?

P4. Is there a relationship between the level of GDP per capita and the value of the HDI index?

P5. Is there a relationship between the level of public debt and the value of the Human Development Index (HDI)?

The study used the method of secondary data analysis. Empirical material was obtained from Eurostat statistical databases. It included data on gross domestic product per capita, public debt, public debt-to-GDP ratio, and unemployment rates in the European Union Member States. The data concerning the Human Development Index were obtained from the World Population Review database. It was developed on the basis of data from the United Nations Development Programme (UNDP). All EU Member States for which data covering the adopted time horizon were available were analysed.

In the research process, the methods of comparative analysis, descriptive analysis and analysis of the relationship between selected socio-economic indicators were used. An effort was made to assess the effects of socio-economic development management in individual Member States. It has also become possible to identify the differences between the analysed economies. The results were presented in the form of graphical summaries. This allowed us to assess the direction of changes taking place in the years 2010-2025. The relationships between selected aspects of economic and social development have been identified.

The analysis of relationships between selected socio-economic indicators was exploratory in nature. It was primarily based on a visual assessment of data distribution and the identification of general patterns and trends occurring between the analysed variables. In the case of the relationship between the level of public debt and the Human Development

Index (HDI), the coefficient of determination (R^2) was additionally applied. This coefficient made it possible to assess the strength of the relationship between the analysed variables. The obtained results should be interpreted as an analysis of the coexistence of phenomena rather than as a basis for drawing causal conclusions.

4. Results

The analyses were aimed at assessing the differentiation of the level of socio-economic development of the European Union Member States. Efforts were also made to identify the changes that will take place in this area over the years 2010-2025. For this purpose, selected economic and social indicators were used. They included gross domestic product per capita, the level of public debt, the ratio of public debt to GDP, the HDI human development index and the unemployment rate. The analysis made it possible to compare the situation of individual EU Member States. In addition, an attempt was made to assess the direction and scale of the changes taking place. In addition, the analysis of the relationship between the level of GDP, public debt and the HDI index made it possible to indicate the extent to which economic development translates into the level of social development and the quality of life of residents. The results made it possible to identify developmental disparities occurring within the European Union. In addition, selected conditions shaping the contemporary socio-economic development of the Member States were assessed.

Figure 1 shows the value of gross domestic product per capita in the Member States of the European Union in 2010 and 2025. The analysis of the data indicates a clear variation in the level of economic development between individual countries. The highest GDP per capita values were recorded in Luxembourg and Ireland. Here, in this case, they significantly exceeded the average for the entire European Union. The index was also high in Denmark, the Netherlands, Austria and Belgium. On the other hand, the lowest values can be observed in Bulgaria, Romania, Croatia and Hungary. This indicates that development differences between the countries of Western and Central and Eastern Europe persist.

A comparison of data from 2010 and 2025 allows us to notice the growth of GDP per capita in most of the analyzed countries. Particularly dynamic growth occurred in Ireland. The value of the index has risen to a level almost twice as high as in 2010. A visible improvement in the economic situation also occurred in Poland, Lithuania, Estonia and Romania. This may indicate a process of gradual reduction of the development gap with the more developed economies of the EU. At the same time, despite the overall upward trend, significant income disparities between Member States persist. This indicates the uneven nature of economic development within the European Union.

The highest GDP per capita values in 2025 were recorded in Luxembourg and Ireland, while the lowest values were observed in Bulgaria and Romania. Among the largest European Union economies, such as France, Italy, and Spain, a moderate but steady increase in GDP per capita was observed compared to 2010. These results confirm the persistence of development disparities among European Union Member States despite the overall improvement in the analysed socio-economic indicators.

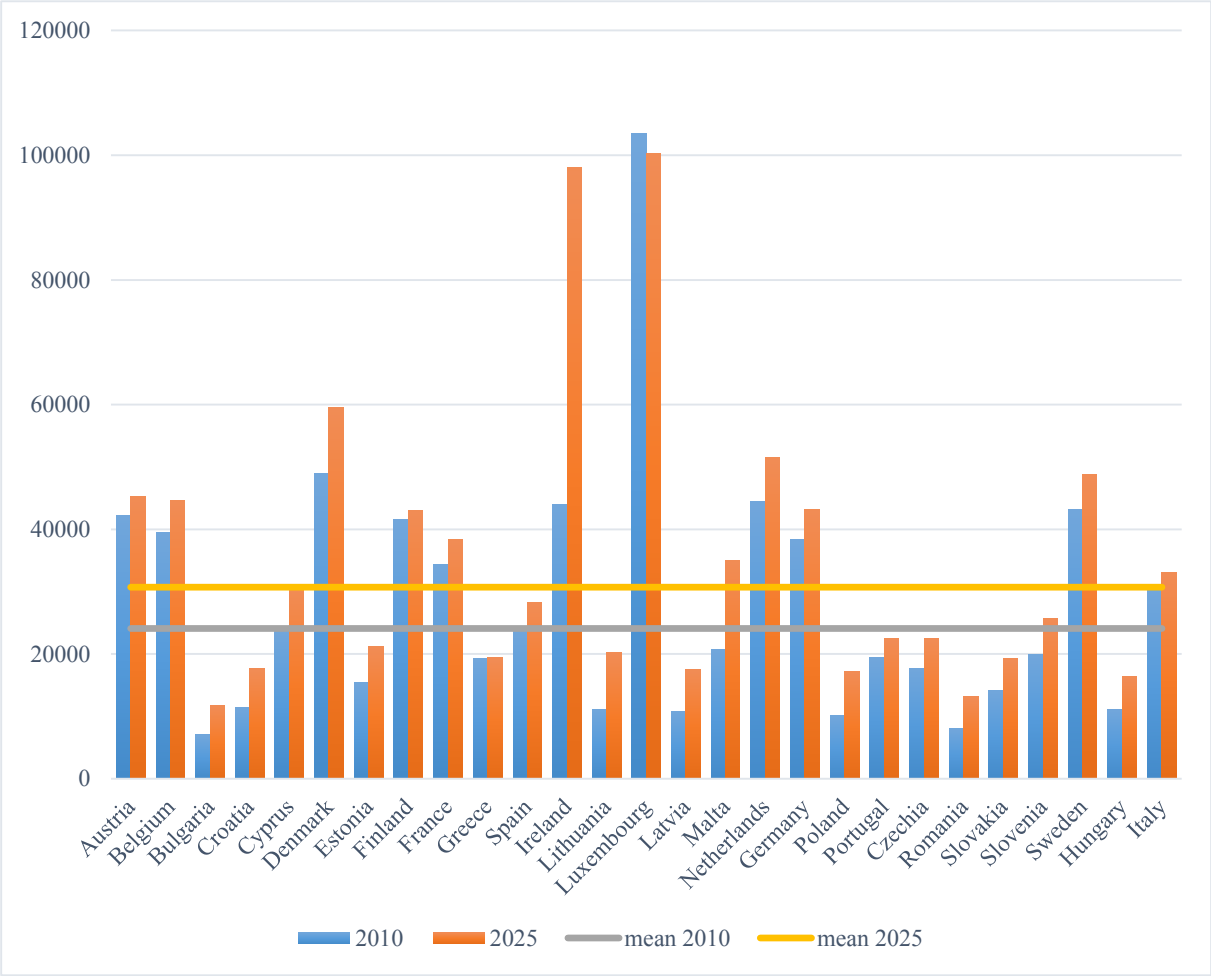

Figure 1. Gross domestic product in the EU Member States per capita at market prices in euros in 2010 and 2025.

Source: Own study based on Eurostat data.

Figure 2 shows the level of public debt in selected EU Member States in 2010 and 2025. It should be emphasized that presenting public debt in absolute values makes it possible to assess the scale of indebtedness of individual economies, but it does not allow for a full evaluation of the burden on public finances in countries differing in population size and economic potential. For this reason, the analysis of absolute values was supplemented with an analysis of the public debt-to-GDP ratio (Figure 3), which enables a more objective comparison of the fiscal situation of European Union Member States. In the analyzed period, an increase in debt was recorded in most countries. At the same time, the highest values were found in France, Italy and Spain. On the other hand, the relatively low level of public debt

remained in the countries of Central and Eastern Europe. Estonia, Latvia and Lithuania were among such countries. The results show that public finances are under increasing pressure in many EU economies.

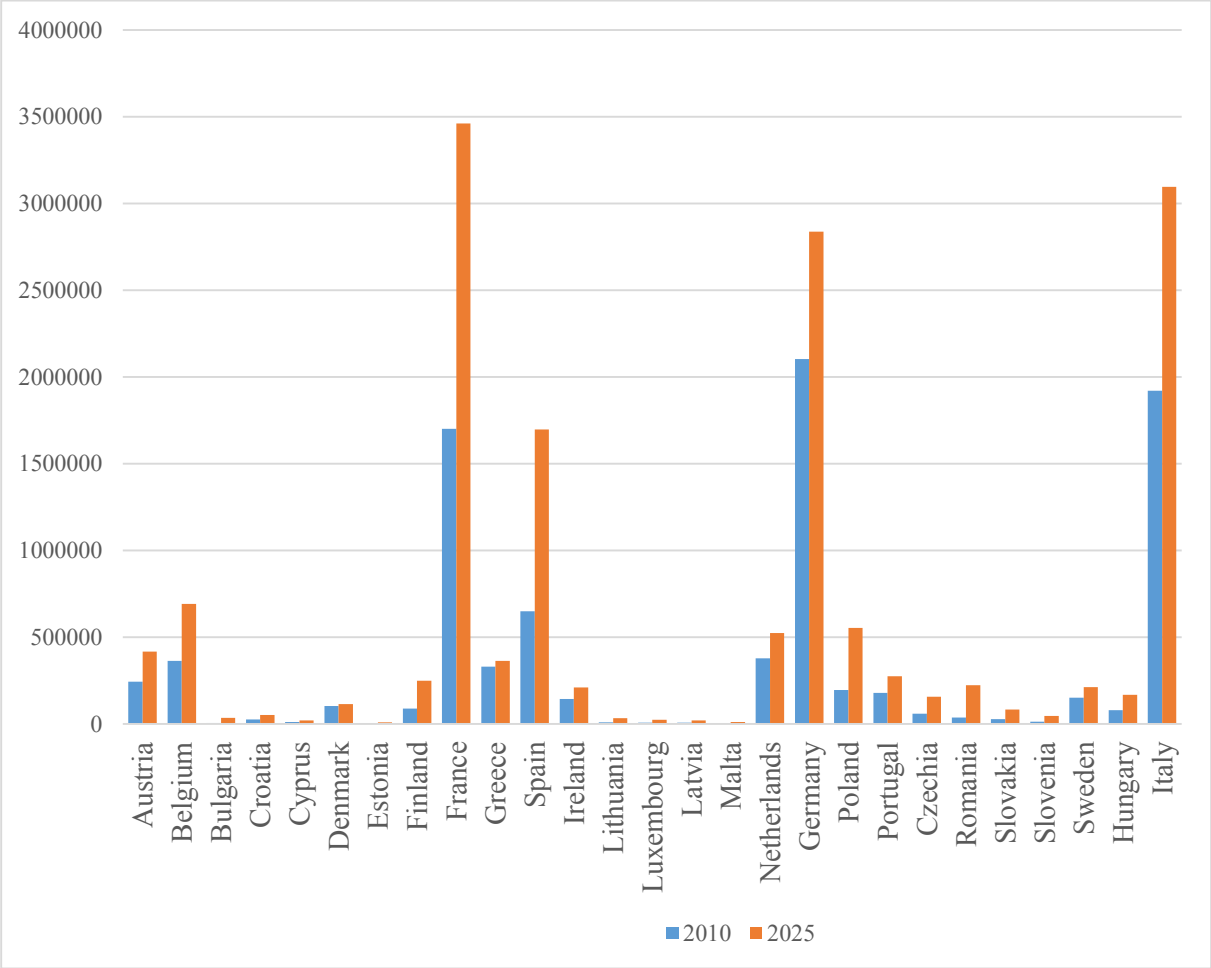

Figure 2. Public debt in EU Member States in 2010 and 2025 (in euro).

Source: Own study based on Eurostat data.

The ratio of public debt to gross domestic product in the EU Member States in 2010 and 2025 is presented in Figure 3. The highest values of the index were recorded in France, Italy and Spain. In these countries, the level of debt significantly exceeded the EU average. On the other hand, the lowest share of public debt in GDP was recorded in Estonia, Bulgaria and the Baltic States. The results show that significant differences in the sustainability of public finances persist between Member States.

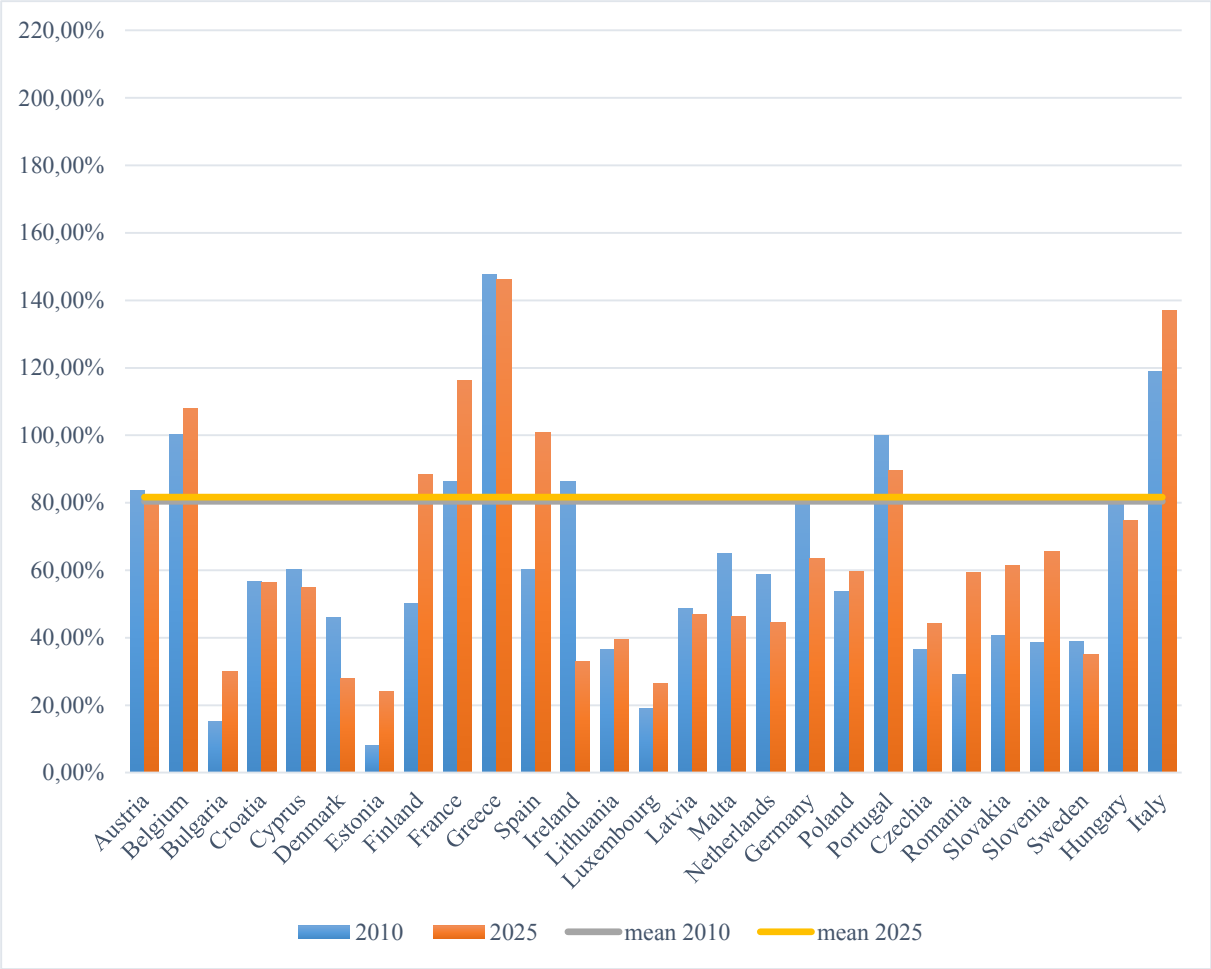

Figure 3. Public debt-to-GDP ratio in EU Member States in 2010 and 2025 (%).

Source: Own study based on Eurostat data.

Figure 4 presents the ranking of the European Union Member States according to the HDI Human Development Index in 2010, 2020 and 2023. In all analysed countries, an increase in the value of the indicator was observed. This proves the improvement of living conditions of residents, the level of education and health. Denmark, Sweden, Germany and the Netherlands achieved the highest HDI values, while Bulgaria, Romania and Hungary achieved the lowest, confirming the persistence of development differences between EU countries.

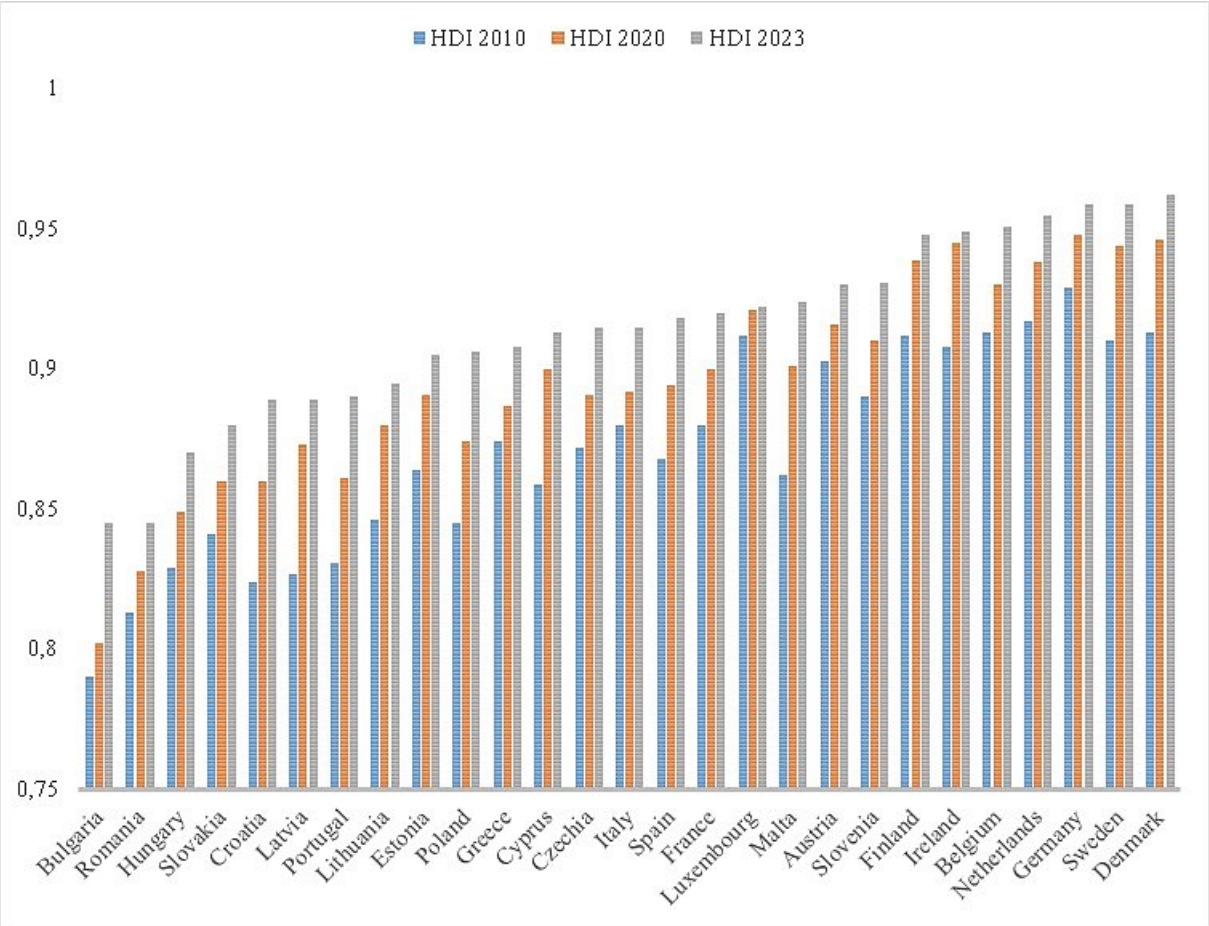

Figure 4. Human Development Index (HDI) – ranking 2010, 2020 and 2023 for EU Member States.
Source: https://worldpopulationreview.com/country-rankings/hdi-by-country

Figure 5 presents the level of unemployment in the European Union Member States in 2010 and 2025. In most countries, a decrease in the unemployment rate can be observed. It is particularly visible in Spain, Greece and the countries of Central and Eastern Europe. In 2025, the values of the indicator were more balanced than in 2010. This indicates an improvement in the situation on European labour markets and greater resilience of economies to crisis phenomena.

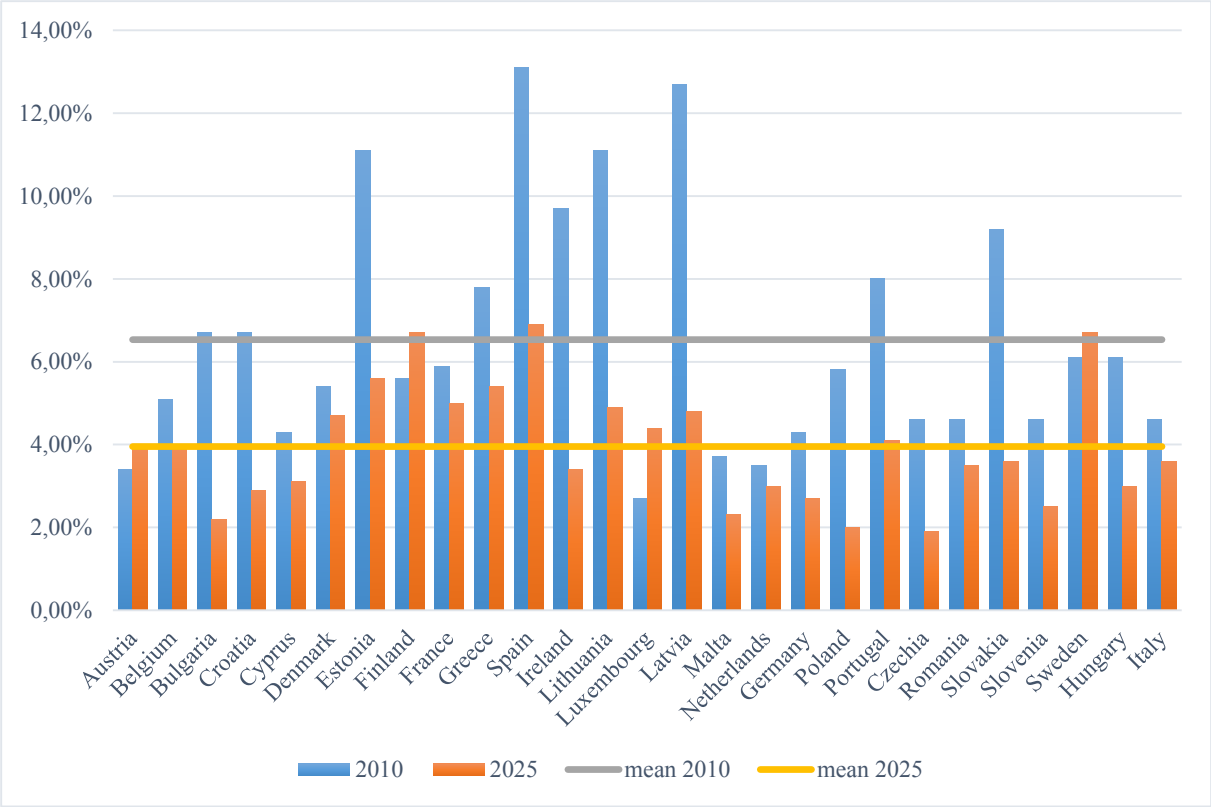

Figure 5. Unemployment rate in the EU Member States in 2010 and 2025 (%).

Source: Eurostat; https://ec.europa.eu/eurostat/databrowser/view/tps00203/default/table?lang=en, 23.04.2026.

Figure 6 shows the relationship between the level of gross domestic product per capita and the HDI in the European Union Member States in 2025. A positive relationship between the analyzed variables was observed. This means that countries with higher levels of economic development tended to also achieve higher HDI values. A particularly favourable situation was recorded in Luxembourg, Ireland and Denmark. In turn, the lowest values of both indicators were recorded in Bulgaria and Romania.

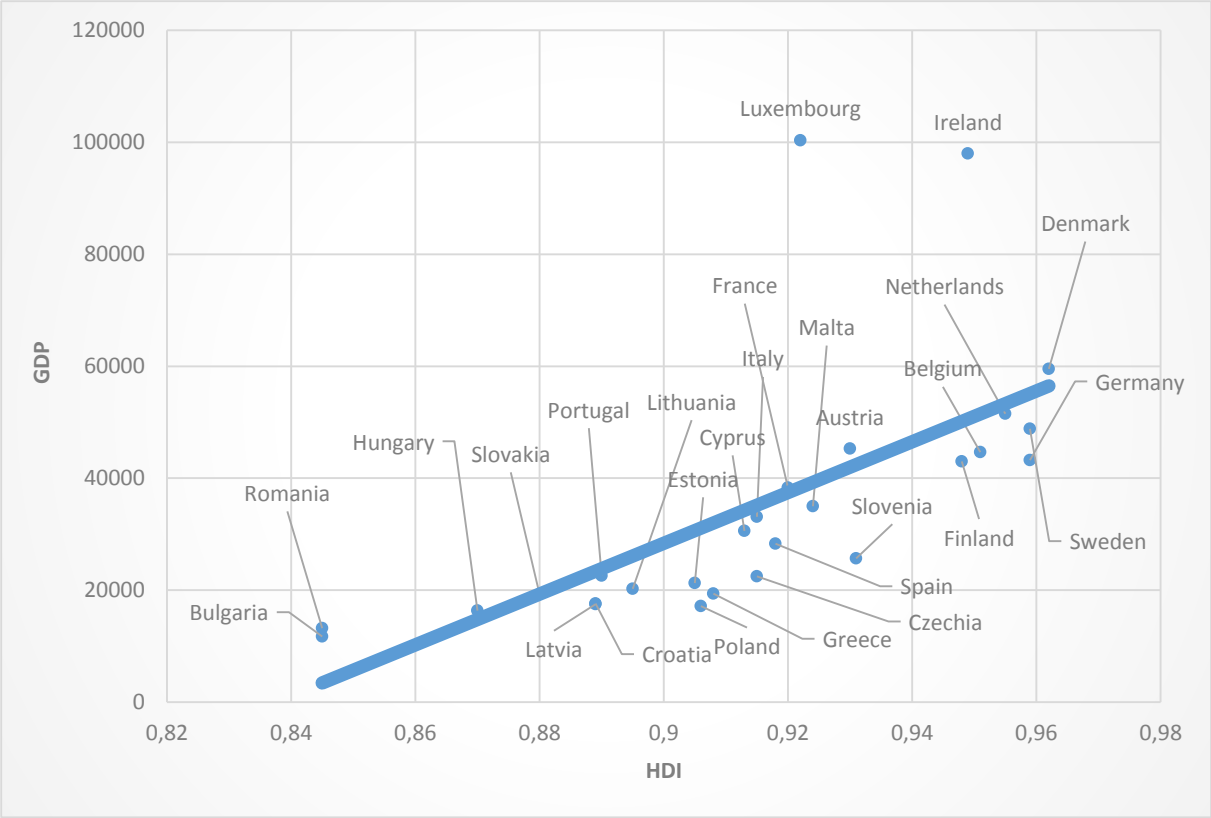

Figure 6. Relationship between GDP and HDI for individual EU Member States (2025).

Source: https://worldpopulationreview.com/country-rankings/hdi-by-country

Figure 7 presents the relationship between the level of public debt and the HDI in the Member States of the European Union in 2025. By analysing the results, it is possible to indicate a very weak relationship between the analysed variables. This is confirmed by the low coefficient of determination ($R^2 = 0.053$). Therefore, it can be pointed out that a high level of social development does not have to be directly related to the size of public debt. In turn, the level of HDI is shaped by a much broader set of social, economic and institutional factors.

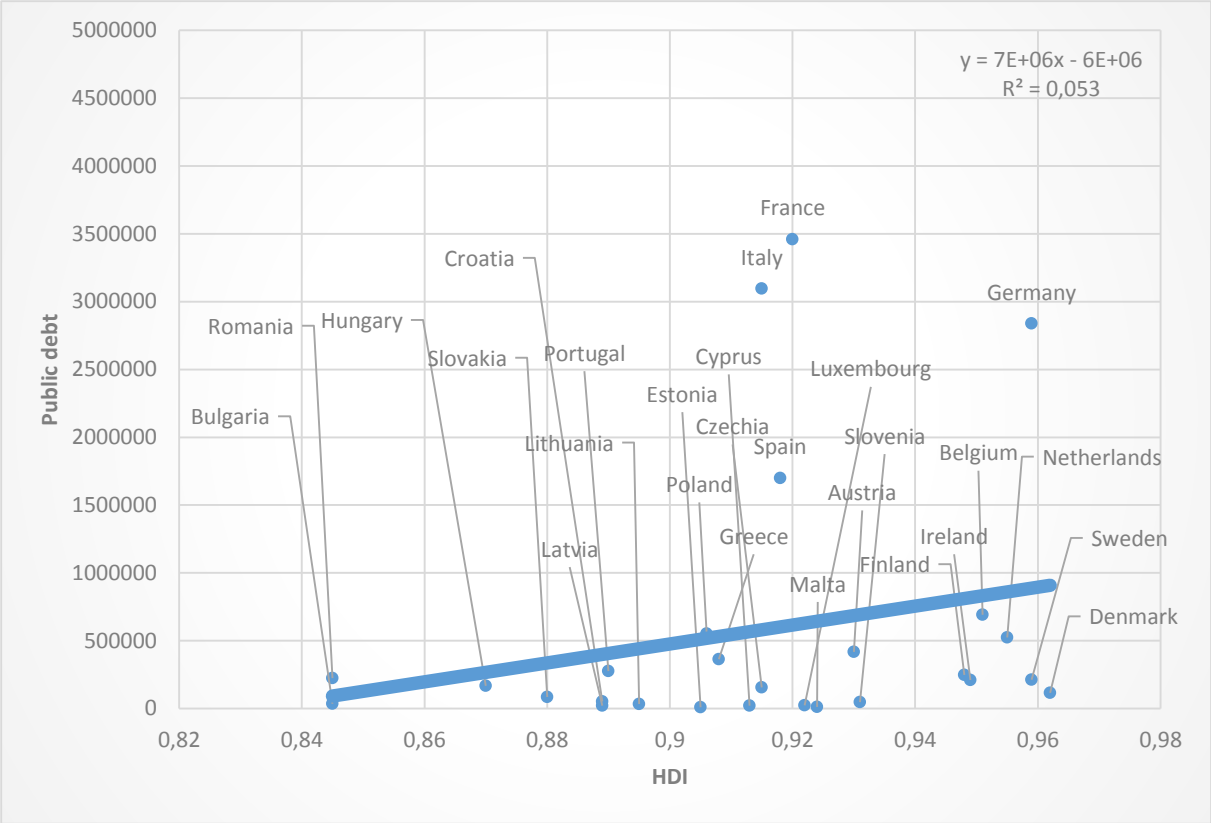

Figure 7. Relationship between public debt and HDI for individual EU Member States (2025).
Source: https://worldpopulationreview.com/country-rankings/hdi-by-country

The findings suggest, it can be indicated that in the years 2010–2025, in most of the Member States of the European Union, there was an improvement in basic socio-economic indicators. An increase in gross domestic product per capita and HDI values can be observed. In addition, there is a decrease in the level of unemployment in many countries. At the same time, an increase in public debt and its relationship to GDP can be observed in some countries. This is particularly evident in the largest economies of the EU. On the basis of the results obtained, it can be indicated that there is a positive relationship between the level of economic development and social development. However, no significant relationship has been demonstrated. Despite the observed positive changes, significant development differences between the countries of Western Europe and the countries of Central and Eastern Europe can still be noticed. This indicates the continuing variation in the level of socio-economic development in the European Union.

5. Discussion

On the basis of the presented data, several important conclusions can be drawn concerning the methods of managing the socio-economic development of the European Union Member States. In the analyzed period, it is possible to point to a systematic increase in the Gross Domestic Product per capita and an improvement in the value of the HDI in most of the surveyed countries. At the same time, a decrease in the level of unemployment was recorded. This means the effectiveness of the implemented development policies and indicates the ability of countries to create conditions that are conducive to the growth of economic and social activity. Based on the results obtained, it can be concluded that despite numerous economic, social and geopolitical challenges, the countries of the European Union maintained the ability to achieve development goals and improve the quality of life of their residents. This can be seen as an important manifestation of effective development management at national and supranational level.

On the basis of the analysis carried out, it can also be concluded that the increase in the level of economic development was accompanied by an increase in public debt in many Member States. Particularly high values of public debt and its relation to GDP were recorded in the largest European economies. These included France, Italy and Spain. On the basis of the cited data, it can be indicated that the implementation of development strategies and counteracting the effects of crises required the involvement of significant financial resources, which remained at the disposal of the public sector. At the same time, there was no clear relationship between the level of debt and the level of social development. Therefore, it can be said that the effectiveness of development management is determined not only by the scale of the financial resources used. The efficiency of their allocation is important here. The ability of public institutions to achieve the assumed social and economic goals is not without significance.

After tracing the results of the research, it is possible to observe a positive relationship between the level of economic development and the social development of the European Union Member States. At the same time, the countries that achieve the highest GDP per capita values belonged to the group of countries characterized by the highest HDI values. This can indicate the existence of a long-term and integrated approach to development management. Despite the observed economic convergence, the differences between the countries of Western Europe and the countries of Central and Eastern Europe are still visible. This means the emergence of a management challenge facing the institutions of the European Union. This challenge is undoubtedly the strengthening of socio-economic cohesion. In addition, it is crucial to create mechanisms to support more sustainable and inclusive development for all Member States.

The obtained results are generally consistent with the research directions presented in the literature. The observed increase in the level of socio-economic development across most European Union Member States is in line with studies highlighting the importance of institutional, social, and economic factors for national development (Leitão, Capucho, 2021; Garina et al., 2019). The identified positive relationship between GDP per capita and the Human Development Index (HDI) may also be considered consistent with previous research emphasizing the coexistence of economic growth and improvements in social well-being (Rahman, Hossain, 2025; Ali et al., 2025). At the same time, the persistent disparities in development levels among European Union Member States confirm that the process of socio-economic convergence has not yet been fully completed. The findings also align with a stream of research emphasizing the importance of sustainable development and contemporary development challenges for the functioning of European economies (Madni et al., 2022; Medeu et al., 2025).

The obtained results may also be interpreted in the light of convergence theory, according to which countries with lower levels of economic development should gradually reduce their development gap in relation to more advanced economies. The observed increase in GDP per capita and the improvement in HDI values in the countries of Central and Eastern Europe may indicate an ongoing convergence process. At the same time, the persistent disparities among European Union Member States suggest that this process has not yet been fully completed. In this context, the European Union's cohesion policy plays an important role. Its objective is to reduce development disparities by supporting infrastructure, social, and economic investments in less-developed regions.

6. Conclusions

On the basis of the presented proposals, recommendations can be made addressed to entities that remain responsible for managing socio-economic development at the level of the European Union and individual Member States. In particular, governance mechanisms aimed at reducing development disparities between countries and regions should be strengthened. It seems reasonable to implement long-term development strategies. They should be based on the monitoring of key social and economic indicators. These include GDP per capita, employment level and HDI. This approach can support more effective management decisions. It also strengthens the effectiveness of implemented public policies.

Recommendations can also be addressed to institutions that are responsible for managing public finances and economic policy. Thanks to the results obtained, it is possible to indicate the need to use an integrated approach to development management. It should take into account both economic and social objectives. Particular importance should be attached to increasing the

efficiency of the use of public resources, developing systems for evaluating the results of public policies and supporting investments that generate long-term social and economic value. Carrying out such activities will lead to an improvement in the quality of public governance. It will also strengthen the ability of countries to respond to contemporary development challenges.

It is certainly possible to point to the need to further strengthen activities related to the management of human capital and the development of society's competences. It is worth investing in education, developing digital competences, supporting innovation and building conditions conducive to professional activity. These activities can be considered an important instrument for increasing the competitiveness of countries, improving the quality of life of the population and building sustainable foundations for sustainable development in the long term. Such moves are necessary from the perspective of managing socio-economic development.

While conducting this analysis, some limitations were encountered. One of them is certainly the use of only secondary data that come from publicly available statistical databases. This limits the possibility of in-depth identification of the causes of the observed socio-economic phenomena. In addition, the analysis was based solely on selected macroeconomic and social indicators, such as GDP per capita, public debt, unemployment rate, and HDI. They did not capture all aspects of the development of the European Union Member States. In addition, the study was cross-sectional and comparative, not allowing for a full determination of cause-and-effect relationships between the analyzed variables. In future research, it would be interesting to expand the scope of analyses to include additional indicators that are related to innovation, quality of institutions, the level of digitization and sustainable development. It would also be reasonable to use more advanced statistical methods. They would allow to identify the direction and strength of the relationship between the phenomena studied.

The analyses carried out may become an inspiration for future research. It will certainly be interesting to identify the factors that affect the pace of socio-economic convergence of the European Union Member States. It is also worth focusing on the analysis of the long-term effects of public policies. It seems reasonable to expand the scope of analyses to include variables related to the level of innovation, digitization of the economy, energy transition, quality of public institutions and the level of human capital. It would certainly be valuable to conduct a study using advanced econometric methods. They will allow for a more precise determination of the strength and direction of the relationship between economic development, social development and the stability of public finances. A particularly interesting research area may be the assessment of the impact of contemporary challenges, such as digital transformation, geopolitical crises or demographic processes, on the future level of socio-economic development of the European Union countries.

It should be emphasized, however, that the research methods applied were descriptive and comparative in nature. Therefore, the obtained results make it possible to identify changes occurring in the level of socio-economic development of European Union Member States,

as well as the relationships observed between them. However – and this should be clearly stressed – they cannot serve as a basis for drawing unequivocal causal conclusions regarding the impact of specific policy measures on increases in GDP per capita, improvements in HDI values, or changes in unemployment levels.

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RESOURCE-BASED DETERMINANTS OF INNOVATION IN POLISH OFFSET PRINTING FIRMS

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Purpose: The purpose of this paper is to identify the relative importance of internal and external resources as determinants of innovation in Polish offset printing firms operating under technological, environmental and market pressure.
Design/methodology/approach: The study is based on a survey of 123 Polish offset printing firms, including 85 firms that implemented innovations within the previous three years. The empirical analysis uses descriptive statistics, the Mann-Whitney U test, Spearman correlations and the Kruskal-Wallis test to examine links between resources, innovation types and outcomes.
Findings: The findings show a high level of innovation activity. Product and process innovations are the most common, while internal intangible resources play a stronger role than external sources. External resources are important mainly as complementary inputs, especially for selected innovation types such as marketing innovations.
Research limitations/implications: The study is limited to Polish offset printing firms and is based on survey data. Future research could extend the analysis to other countries, include longitudinal data and compare offset printing with other manufacturing industries.
Practical implications: Managers should strengthen intangible internal assets, especially knowledge, employee competences, managerial and technological expertise, and in-house R&D, while using external resources selectively as complementary sources of innovation.
Social implications: The findings support the sustainable development of a strategically important industrial sector by indicating how firms can maintain competitiveness while responding to technological, market and environmental pressures.
Originality/value: The paper contributes to innovation and resource-based theory by clarifying how resource configurations shape innovativeness in a mature but transforming manufacturing sector that remains under-researched in management studies.
Keywords: innovation; firm resources; intangible resources; competitive advantage; offset printing.
Category of the paper: Research paper.

1. Introduction

Innovation in the printing industry plays a significant role in shaping the development prospects of the Polish economy. Over recent decades, the industry has recorded dynamic growth (Cetera, 2015), positioning Poland as a major global player with the sixth-largest share in world exports with revenue exceeding PLN 7 billion (Poland on the global map..., 2026). Much of this global competitiveness stems from the offset printing sector, which accounts for a substantial share of export value. The offset printing sector remains an important part of industrial production in Poland, particularly because of its role in high-volume packaging for food, pharmaceutical, and consumer goods industries. Despite the rapid technological progress of digital printing, offset continues to dominate applications requiring high quality, colour consistency and cost efficiency in long production runs, where digital technologies still face performance limitations (Yilmaz, 2018).

Although the process is technologically mature - defined as the indirect transfer of an image from a plate to a rubber blanket and then onto a substrate (Bălan, 2021) - the sector is currently undergoing profound transformation driven by competitive, environmental and organisational pressures. These forces shape the conditions under which firms must innovate to maintain operational efficiency, cost advantages and market position.

A major driver of innovation in offset printing is the growing competitive pressure from increasingly efficient and versatile digital printing technologies, often perceived as faster, more flexible and easier to operate (Mirković, 2024). To sustain its advantages, the offset sector must continuously improve process efficiency, enhance compatibility with evolving substrates and inks (Pogačar, 2023), and aggregate print orders through diverse sales channels to maximise run lengths and fully leverage the speed and cost benefits of offset production. These tendencies are accompanied by broader structural changes, including vertical integration and cross-industry convergence, which strengthen the strategic position of firms operating within offset-based production systems (Magadán-Diaz, 2021).

Environmental and regulatory pressure constitutes another important source of innovation. Traditional offset printing involves the use of chemicals, including heavy metals, that increasingly fall under regulatory scrutiny, generating strong incentives to reduce environmental impact (Viluksela, 2010). Although the sector has long been associated with circular-economy practices due to the widespread recyclability of paper (Dumea, 2009; Vukoje, 2021), the adoption of more ecological inks and advanced curing technologies complicates recycling processes, as new formulations tend to bond more strongly with substrates (Rojas García, 2023; Yang, 2022; Klemenčić, 2023; Strižić Jakovljević, 2024). As a result, printing companies must increasingly integrate environmental considerations into their technological and organisational development strategies, making sustainability a key dimension of innovation.

A third transformative force reshaping the sector is the evolution of business models. Recent studies highlight that competitive advantage increasingly emerges from service-oriented and data-driven models rather than exclusively from product-based strategies, driven by digitalisation, workflow automation and hybrid offerings combining print and digital services (Magadán-Diaz, 2021; Salwin, 2020; Meissner, 2021; Afifa, 2022). This shift requires not only technological innovation, but also organisational and marketing innovations, including new forms of customer engagement, process integration and internal capability development.

Taken together, these trends demonstrate that sustaining and strengthening the role of the offset printing sector requires continuous implementation of product, process, organisational and marketing innovations. Yet, despite extensive research on the transformation of the printing industry, relatively little is known about the specific conditions that shape innovation in offset printing firms - particularly regarding the role and configuration of organisational, technological and relational resources. The literature does not provide a clear answer as to whether internal resources (Magadán-Diaz, 2021; Afifa, 2022) or external resources such as cooperation networks and institutional support (Salwin, 2020; Meissner, 2021) form the primary foundation of innovative capacity in this sector. Moreover, the relationship between different types and levels of innovation and the competitive benefits derived from them remains insufficiently explored.

The present study addresses these gaps by examining how innovations implemented by Polish offset printing companies contribute to their competitive advantage in the context of technological, environmental and business transformation. The analysis covers the structure and scale of implemented innovations, including new or significantly modified product, process, organisational and marketing solutions and evaluates their impact on operational performance, product development and market expansion. Particular emphasis is placed on identifying which types and degrees of novelty generate the most substantial competitive gains, enabling offset printing firms to maintain strong market positions despite growing competition from digital technologies. The article proceeds by outlining the theoretical foundations of the study, describing the research methodology, presenting the empirical findings and discussing their implications for both industry practice and innovation theory.

2. Innovation and Firm Resources

Innovation is one of the most frequently discussed concepts in management studies, and its importance continues to grow as it is widely regarded as a primary driver of entrepreneurial development and economic growth. Despite the extensive attention devoted to innovation, the academic literature provides no universally accepted definition of the term. Innovation may be understood as a concrete outcome of human activity (Glińska-Neweś, 2017),

a novelty itself (Matjaz, 2005), a process leading to novelty (Courvisanos, 2007), or a result of introducing novelty into practice (Quintane, 2011). These perspectives highlight the central role of "newness", yet they differ in whether novelty is treated as the cause, the result, or the defining identity of innovation.

A major attempt to unify these perspectives is offered by the Oslo Manual (OECD/Eurostat, 2018), which defines innovation as a new or significantly improved product or process (or a combination of both) that is made available to users (customers or internal users) or implemented in practice. The Manual distinguishes four types of innovation: product, process, organisational and marketing innovations. According to this definition, a change qualifies as an innovation only if it (1) represents novelty and (2) is implemented or delivered to users.

The capacity of firms to innovate is determined by the interaction of internal and external resources. In Three-Factor Innovation Development Model (TRI), innovation-driven growth occurs when three interconnected elements are present: (1) innovation capability (the resources a firm possesses and its ability to deploy them), (2) innovation propensity (the motivation and readiness to introduce new solutions), and (3) the external environment, which stimulates and shapes the direction of change (Stanisławski, 2022). This model underscores that innovation depends not only on resource availability but also on organisational willingness and contextual conditions.

Building on this framework, existing research seeks to identify which categories of resources most strongly determine innovation outcomes in practice (Abdulsamad, 2025; Veiga, 2024; Audretsch, 2023). This is important primarily for the search for optimal strategies for the innovative development of companies (Abbass, 2025; Perotti, 2025; Hock-Doepgen, 2025).

However, the literature does not provide consensus on which categories of resources - internal or external, material or immaterial - are the stronger determinants of innovation. Evidence suggests that the answer depends heavily on the firm's sector, institutional environment, maturity and technological profile.

Research by Zhu et al. on science-based firms shows that internal scientific capabilities, such as in-house basic research, substantially increase innovation performance. External resources (e.g., collaboration with research institutions) also matter, but their effectiveness depends on the firm's ability to absorb and utilise external knowledge. For these organisations, internal intangible resources are a stronger driver of innovation than external or material resources (Zhu, 2025). Similar patterns are found in R&D-intensive manufacturing sectors such as the pharmaceutical one. Wu et al. demonstrate that internal R&D investments strongly correlate with higher innovation output (e.g., patents), whereas external R&D expenditure has a weaker or negligible effect. Large firms treat external partnerships as complementary, while small firms rely on them only as a transitional mechanism to build internal R&D capacity. These studies indicate that material resources - especially financial resources - are effective only when supported by internal intangible capabilities that ensure their productive use (Wu, 2022).

A comprehensive review by Mališić et al. confirms that internal determinants such as strategy, organisational structures, human-resource practices and culture constitute the foundation of innovation activity. Human-resource management practices that foster knowledge absorption - such as interdisciplinary teams, appropriate decision-making processes and job rotation - play a central role in building dynamic capabilities. Organisational culture, understood as shared values and norms that guide behaviour, communication and decision-making, is also a significant determinant of innovation (Mališić, 2025). Case-based evidence shows that knowledge-sharing cultures strongly facilitate innovation implementation (Lee, 2018).

These findings emphasise that knowledge and the firm's ability to acquire, develop and apply it are essential for innovation. Consequently, the external environment plays a crucial role, as it shapes the opportunities for firms to access complementary knowledge. The strength of institutional surroundings determines whether external or internal resources become more important. Using process innovation as an example, Phung et al. demonstrate that having an innovation strategy - regardless of whether it is internally or externally oriented - always supports innovation, but the importance of external resources increases in stronger institutional environments. In weak environments, internal resources become more critical (Phung, 2021). Thus, the more favourable the external conditions, the lower the threshold for achieving innovation capability, because firms do not need to accumulate large internal knowledge bases to innovate.

The above suggests that the importance of individual resources depends on the specific organizational context, particularly the nature of the organization's environment. This relationship is explored in further empirical research.

Nguyen and Minh's review adds further evidence that external knowledge sources generally exert a positive influence on innovation performance. External resources reduce the cost of exploring new solutions, accelerate problem solving and allow firms to understand emerging challenges more rapidly (Nguyen, 2023). Their analysis also shows a global statistical increase in the importance of external knowledge, consistent with the growing relevance of open-innovation approaches (Perotti, 2025).

External resources are therefore not only an important source of innovation but also a necessary component of contemporary innovation strategies. By sharing risk and development costs with partners, firms can reduce the financial burden of innovation and shorten product-development cycles (Audretsch, 2022). No organisation today holds a monopoly on knowledge, even within narrow domains, which makes external openness an important determinant of competitive success.

The literature also suggests the existence of an optimal balance between internal and external resources a threshold that may vary by industry and sector. In European contexts, external R&D collaboration, especially with scientific institutions, improves product innovation outcomes (Carboni, 2021). However, beyond a certain level of dependency on external sources, benefits diminish and excessive reliance may lead to coordination problems and inefficiencies ("over-outsourcing") (Carboni, 2021).

Over the past decade, there has been growing attention to recombinant innovation, defined as innovation arising from the novel combination of existing knowledge elements (Cecere, 2014). Zhao et al. conceptualise innovation as a stochastic process of recombining ideas, where more complex combinations may yield greater returns (Zhao, 2024). Some researchers argue that recombination is a primary mechanism of technological evolution (Goodman, 2025). The increasing relevance of recombination reinforces the role of external sources of knowledge and diverse collaboration networks. Empirical studies show that broader technological networks, more intensive cooperation and higher diversity of information sources contribute to improved innovation performance (Keil, 2008) and ultimately to stronger competitiveness (Audretsch, 2023). The effectiveness of recombinant innovation depends not only on the number of external partners but also on the multiplicity and heterogeneity of knowledge bases on which firms rely.

Incorporating these insights into the three-element model of innovative development model (Stanisławski, 2022) leads to a refined interpretation of the conceptual framework supporting this study. The relative importance of internal versus external resources - and of material versus intangible ones - is not universal but depends on industry characteristics, the institutional environment and the firm's strategic orientation. Understanding this configuration is essential for analysing innovation development in the offset printing sector, where technological maturity, environmental pressures and evolving business models collectively shape resource structures and their effects on innovation outcomes. Figure 1 summarises these relationships by illustrating how different categories of resources, environmental conditions and innovation-related benefits jointly influence both the capability and the propensity to innovate.

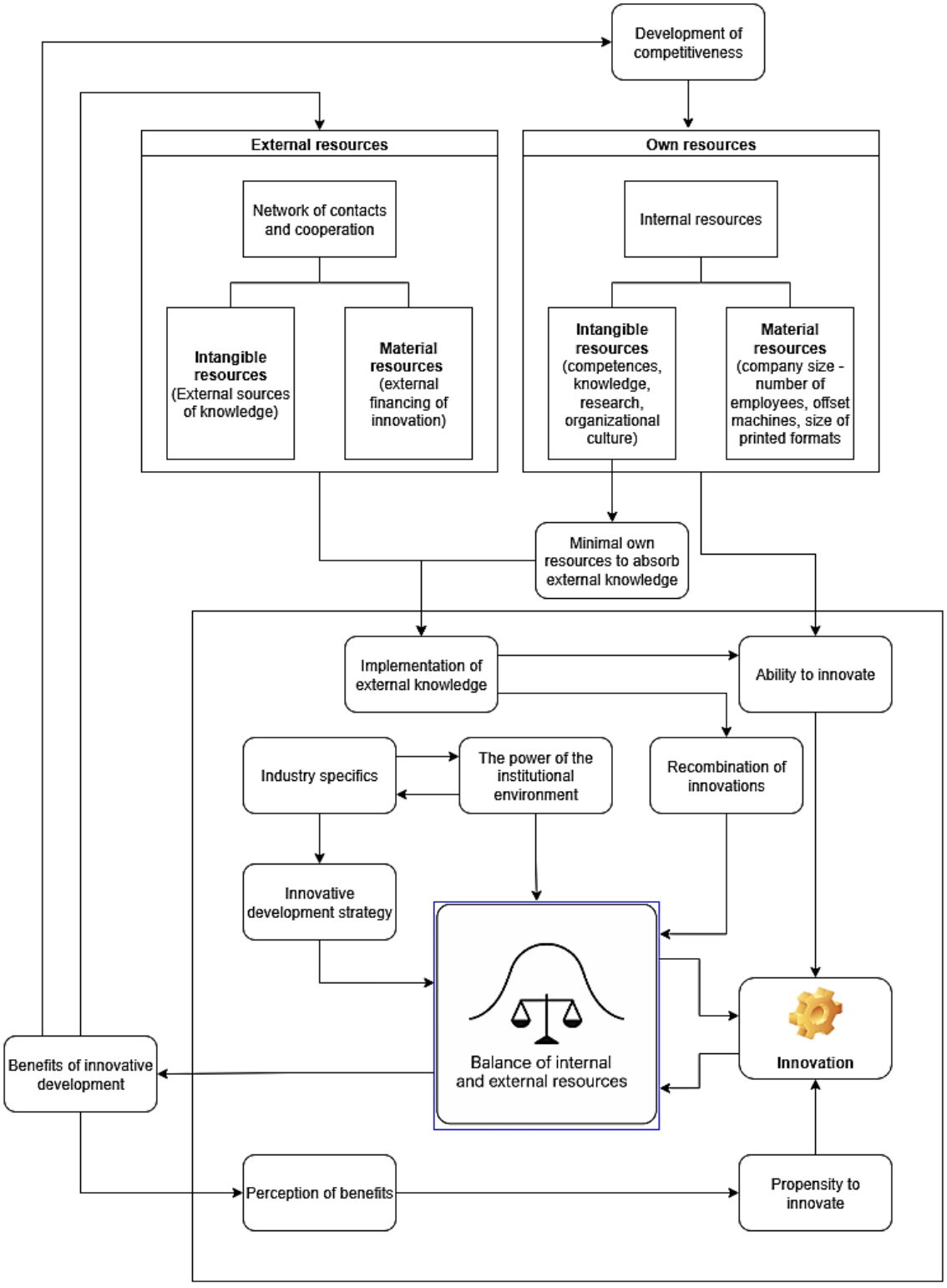

Figure 1. Factors shaping the innovative development of a firm based on the literature review.

Innovation and the development of an enterprise's competitiveness are therefore the result of balancing internal and external resources, the ability to absorb and use knowledge from the environment, which together determine the ability to create and implement innovations.

3. Drivers of Innovation in the Offset Printing Sector

Identifying the likely importance of specific factors within a particular industry requires defining them in the context of the processes that shape innovation-oriented development strategies in that sector (Figure 1).

The offset printing sector is not currently gaining significance on a global scale. The worldwide printing industry is undergoing major transformations, driven particularly by digitalisation, which is reflected in the shift from offset to digital printing. Digital printing technologies offer several advantages over offset, especially in enabling small-scale printing, on-demand printing outside a dedicated printing plant, and generally lower energy use and waste generation (Mirković, 2024).

At the same time, offset remains widely used because the advantages of digital printing diminish with increasing print volumes (Sesli, 2023; Phillips, 2008). While the print runs of books and especially newspapers (are generally not increasing), the demand for large-scale packaging production is certainly not declining (Strižić Jakovljević, 2024). Traditional offset printing provides excellent detail quality for these and similar applications, typically superior to that of large-scale digital printing (Vukoje, 2021; Spiridonov, 2020).

Despite the visible decline in the relative importance of offset printing, numerous innovations can be observed in this sector, particularly process innovations (Hauck, 2015). Alongside competitive pressure from digital printing, an important driver of such innovations is the green transition and the need to reduce environmental impact (Viluksela, 2010). Among the most significant developments is the digital transformation of offset printing firms toward Industry 4.0 solutions (Salwin, 2020), particularly through the implementation of Internet of Things technologies (Meissner, 2021), while maintaining offset-based production. Business models are also evolving, with growing diversification of services offered by printing houses, leading to hybrid business models - especially the product–service model (Magadán-Diaz, 2021). In these models, printing firms are transformed from providers of printed products into providers of printing, design, publishing and even creative services.

In general, the preferred business model in offset printing involves a shift from production-centric to digitally oriented market strategies, implemented through websites and social media applications (Afifa, 2022). A key benefit of this approach is the expansion of the customer base and sales channels, including entry into new markets that may be geographically distant from the printing plant itself (Magadán-Diaz, 2021).

This transformation is not limited to printing firms themselves but also influences their interactions with technology providers. A parallel shift is occurring from product-oriented to service-oriented models among machine and technology suppliers, who no longer merely sell equipment but increasingly provide production capacity as a service, actively shaping the processes and business models of printing firms (Salwin, 2020). As a result, the offset printing

firm evolves from a recipient of products (machines, materials) and a supplier of printed goods into both a service user and a service provider.

These phenomena are illustrated in Figure 2. The figure shows that each of the identified cause–effect areas require competitive firms to undertake comprehensive, dynamic and far-reaching changes, which can be broadly classified into the four main types of innovation: product, process, organisational and marketing innovations.

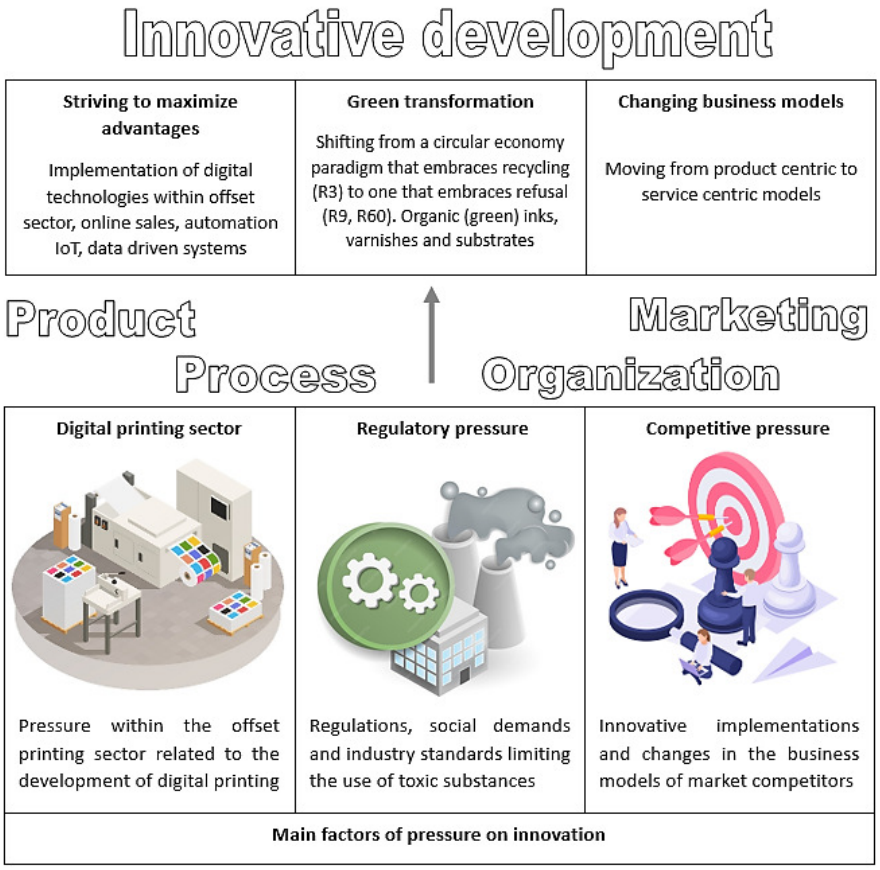

Figure 2. Phenomena stimulating innovation in the offset printing sector.

Source: own elaboration.

One may argue that although offset printing is technologically mature and losing ground to digital printing, the sector is becoming increasingly knowledge-intensive and supported by a growing institutional environment. Consequently, innovations in this sector are likely to rely increasingly on external rather than internal resources. However, this relationship remains insufficiently studied. In the case of the offset printing sector, dynamics of innovation development take on a specific form shaped by technological and market-specific factors.

In the printing industry, correlations have been observed between past innovation implementation and the likelihood of subsequent innovations (Rothenberg, 2007). This aligns with the logic of the Three-Factor Innovation Development Model, in which innovation depends on capability (particularly internal and external resources) and propensity (the perceived role of innovation in improving firm performance). Nonetheless, the role of resources has not been extensively examined in this sector, especially in offset printing.

It appears likely that internal and intangible resources play a particularly important role in the printing sector, including offset, as some studies suggest that a certain minimum level of know-how - achievable even in small firms - is essential for innovation to occur (Reyes-Rodríguez, 2022). Earlier research even indicates that the printing industry has historically exhibited substantial variation in managerial attitudes and organisational cultures, influencing the pace of innovation adoption (Coleman, 2012).

Nevertheless, sustaining competitiveness in this sector requires continuous adaptation, leading to a range of innovations within offset printing firms. Despite these indications, the specific role of different categories of firm resources as determinants of innovation in the printing sector - and particularly in offset printing - remains insufficiently defined.

Although these observations help indicate which types of resources may contribute to innovation in the printing industry, the role of specific resource categories as determinants of innovativeness remains insufficiently defined, particularly in the context of the offset printing sector. Existing studies highlight multiple relationships between internal and external resources, as well as between material and intangible assets, yet they do not provide a clear or comprehensive explanation of how these categories shape the innovative development of firms operating in this technologically mature and increasingly knowledge-intensive industry. This lack of clarity becomes especially relevant considering the ongoing digital transformation, the growing importance of external knowledge sources and the strategic pressures affecting the sector.

To address this gap, the present study formulates a set of research hypotheses that reflect the potential influence of different resource categories on the innovation performance of offset printing firms. These hypotheses are integrated into the conceptual framework and are intended to capture both the complexity and the diversity of resource dependencies observed in the offset printing sector:

H0. Firm resources, including relationships with external entities and the strategic orientation of printing companies, have a positive effect on the innovative development of the offset printing sector.

H1. The implementation of innovations by offset printing firms is influenced by specific internal and external resources.

H2. Internal firm resources are more important for innovative development than external resources.

H3. Material resources are more important for a firm's innovative development than intangible resources.

H4. Different types of innovation - product, process, marketing and organisational - are shaped by distinct internal and external determinants.

These hypotheses, which collectively form the basis for the empirical analysis, are incorporated into the research model presented in Figure 3, illustrating the assumed relationships between resource categories and innovation outcomes in the offset printing sector.

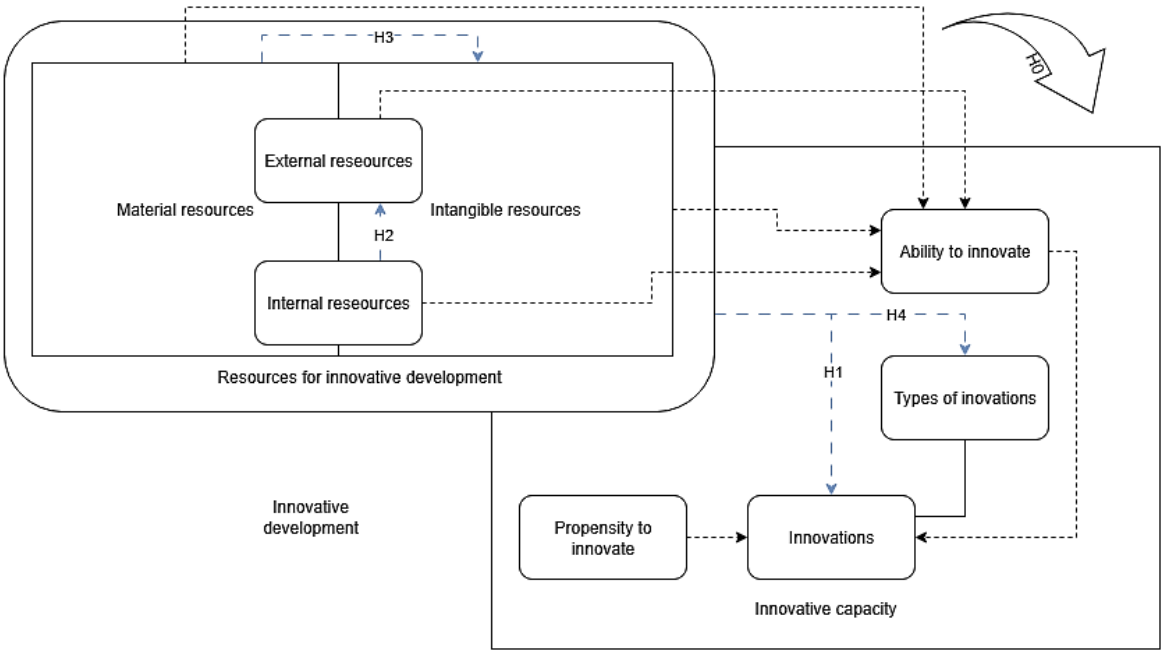

Figure 3. Research model indicating the proposed research hypotheses.

Source: own elaboration.

The above figure incorporates the assumption that the factors of innovation are the areas of external (environmental) and internal (own) resources as well as the tendency and readiness to use them (propensity to innovate), which reflects the Three-Factor Model of Innovative Development (Stanisławski, 2022).

4. Research Methods

4.1. Subject and Method of Study

The research was conducted among Polish printing companies (physically located in Poland) equipped with at least one offset printing machine. Accordingly, entities that did not operate offset presses - those working exclusively with digital printing or located abroad - were excluded from the study (in the case of multinational firms, only the Polish operations were considered).

Data collection was carried out using an online survey administered between March and May 2024 through a structured questionnaire hosted on a web-based platform (Google Forms). A total of 123 responses were obtained from representatives of offset printing companies across the country (Table 1).

Table 1.
Characteristics of the research sample

Factor	Number of answers (n = 92)
Company size	
Micro	9 (7,32%)
Small	60 (48,78%)
Medium	49 (39,84%)
Large	5 (4,07%)
Dominant market	
Global	7 (5,69%)
National	42 (34,15%)
International	53 (43,09%)
Regional	20 (16,26%)
Local	1 (0,81%)
Dominant printing profile (focus sector)	
Books / magazines / art	24 (19,51%)
Labels (including in-mould labelling – IML)	6 (4,88%)
Forms / personalisation	4 (3,25%)
Packaging (food and non-food)	32 (26,02%)
Advertising	56 (45,53%)
Newspaper	1 (0,81%)
Number of offset printing machines	
1-2	72 (58,54%)
3-4	31 (25,20%)
5-6	18 (14,63%)
7 or more	2 (1,63%)

Source: own elaboration.

Table 1 shows that the surveyed enterprises differ in terms of resources, but small and medium-sized enterprises dominate among them.

4.2. Statistical Methods

Statistical methods were used to describe the distribution of responses and the structural characteristics of the surveyed firms. The Mann-Whitney U test (Mann, 1947), a semi-parametric test, was applied to identify between-group differences. The jamovi® statistical software (2024) was used to facilitate hypothesis testing based on data from the 85 companies that had implemented innovations (The jamovi project, 2024).

Initially, the Mann-Whitney U test was employed to determine whether firms implementing specific types of innovation - product, process, marketing, organisational and recombinant - experienced statistically significant, measurable benefits compared with firms that did not implement these innovations. The test also examined between-group differences regarding specific benefits associated with innovation development.

At each stage of hypothesis testing, the p-value was used to determine the statistical significance of differences between groups, while effect size was measured for the second and third analytical tasks.

5. Results

5.1. Description of the research sample

A total of 123 responses were obtained from Polish companies operating in the offset printing sector, representing a broad cross-section of firms differing in size, market orientation and production profiles. Among these respondents, 85 firms (69.11%) reported having implemented at least one form of innovation within the past three years, indicating a relatively high and widespread level of innovation activity across the sector. As illustrated in Figure 4, product innovations were implemented by 43.09% of firms, process innovations by 39.02%, organisational innovations by 33.33% and marketing innovations by 23.58%. This distribution highlights both the overall prevalence of innovation in the offset printing sector and the varying emphasis placed on different innovation types, with product and process innovations being the most common.

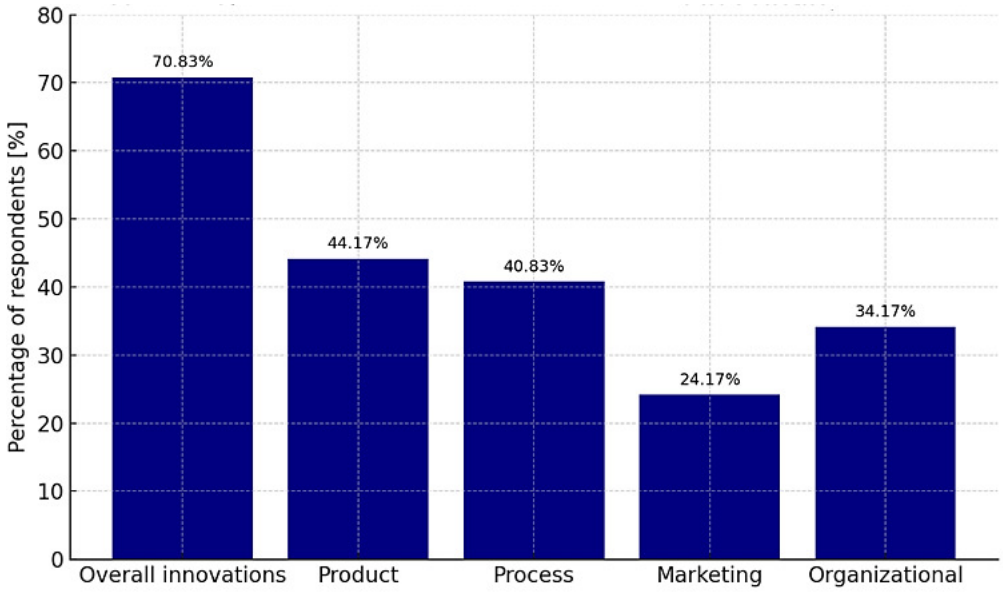

Figure 4. Frequency of innovation implementation in the surveyed offset printing houses.
Source: own elaboration.

The data were collected from all seventeen regions of Poland and were relatively evenly distributed geographically. Most innovative firms in the Polish offset printing sector are medium-sized (54.1%) or small enterprises (36.5%). It is noteworthy that medium-sized companies are disproportionately represented among innovators (54.1%) compared with the overall sample (39.8%). Conversely, innovations are implemented less frequently in small firms (36.5% vs. 48.8%) and micro-enterprises (3.53% vs. 7.32%). This pattern shows that while medium-sized firms lead in innovation activity, small and micro-enterprises also play an active role, demonstrating that innovation is not limited to larger organisations.

Innovative firms are located primarily in metropolitan areas or regional capitals (40.00%) and in larger cities with more than 100,000 inhabitants (22.35%). This urban concentration is more pronounced among innovators (40.00%) compared with the entire sample (35.77%).

Most innovative firms operate in international (57.65%) or national markets (30.59%), with minimal focus on regional or local markets. This global orientation is more significant among innovators (57.65%) than among all surveyed firms (43.09%). In contrast, innovators place less emphasis on regional or local markets, even though these markets are relatively important for the broader sample (17.07%).

The sectoral distribution among innovative firms indicates that packaging printing (37.65%) and advertising (29.41%) dominate, followed by book printing (23.53%). Innovative firms are more strongly represented in packaging printing compared with the overall sample (37.65% vs. 26.02%), but are less engaged in advertising printing (29.41% vs. 45.53%).

Production infrastructure further highlights the number and types of machines as key structural characteristics. The largest group of innovators consists of firms with 1-2 offset presses (45.88%), followed by those with 3-4 machines (31.76%). Fewer firms operate five or more presses, although innovators generally possess larger machine parks. For example, 22.35% of innovators use five or more offset presses, compared with only 16.26% in the overall sample. This indicates that while many innovative firms operate with relatively few machines, larger machine parks are more common among innovators.

The dominant printing format further differentiates firms into three main groups. Format B1, used by 57.65% of innovators, is the most common, reflecting the advanced capabilities of offset machines for large-format production such as posters and packaging. Format B0, found in 7.06% of innovators, supports even larger sheet sizes. These formats highlight the concentration of innovative firms on large-scale, high-value production.

Format B2, used by 23.53% of innovators, is the second most common and is typically associated with medium-sized production such as brochures, catalogues or books. Smaller formats - including A1 (5.88%), A2 (2.35%) and B3 (3.53%) - are used less frequently and usually serve specialised or small-volume products such as promotional materials or personalised prints.

5.2. Enterprise resources as determinants of innovativeness

In verifying hypothesis H1, the structural differences observed between firms that implemented innovations and those that did not (Table 2) were confirmed using the Mann-Whitney U test. Statistically significant discriminatory power was identified for the operational market ($p < 0.001$, $r = 0.693$, large effect size), number of employees ($p < 0.001$, $r = 0.556$, large effect size), dominant printing sector ($p < 0.001$, $r = 0.576$, large effect size), number of machines ($p < 0.001$, $r = 0.425$, large effect size) and dominant print format ($p < 0.001$, $r = 0.540$, large effect size). Company location, however, was not significant ($p = 0.313$, $r = 0.110$).

To further verify the hypothesis, the relationships between enterprise resources and the characteristics of implemented innovations were analysed. Partial correlations using Spearman's rho demonstrated statistically significant associations between the degree of novelty (novelty at firm, national or global scale) of product innovations and the number of machines ($p = 0.001$), between the degree of novelty of process innovations and the number of employees ($p = 0.012$) as well as the number of machines ($p < 0.001$), and between the novelty of organisational innovations and the dominant print format ($p = 0.009$). Additionally, the novelty of product innovations correlated with the novelty of organisational innovations ($p = 0.009$), the number of machines correlated with the number of employees ($p < 0.001$) and the number of employees correlated with dominant print format size ($p < 0.001$).

Spearman's partial correlation analysis also revealed statistically significant positive relationships between the novelty of innovations and their sources. For product innovations, higher novelty was associated with the use of scientific research ($p = 0.021$) and sector events ($p = 0.016$). For process innovations, significant correlations were found for sector events ($p < 0.001$) and imitation ($p = 0.026$). For marketing innovations, the novelty of solutions correlated with customer suggestions ($p = 0.027$) and the acquisition of intellectual property rights or licences ($p = 0.015$). For organisational innovations, novelty was significantly associated with in-house market research ($p = 0.004$), customer suggestions ($p = 0.022$) and the acquisition of intellectual property or licences ($p = 0.002$).

Among the firm's resources relevant to hypothesis H1, knowledge resources - alongside material resources such as machine capacity - play a pivotal role. To assess their influence, the relationships between the types of innovation implemented and the knowledge sources used by firms were examined. The Kruskal–Wallis test showed that several innovation sources significantly contributed to measurable benefits derived from innovation: in-house market research ($p = 0.042$), customer suggestions ($p = 0.035$), ideas generated by the sales force ($p = 0.039$), internal R&D activities ($p = 0.003$), business support institutions ($p = 0.045$) and scientific research ($p = 0.012$). These findings are summarised in Table 3.

Table 3.
Differences between firms that achieved measurable benefits from innovation development and those that did not, in terms of the importance of innovation sources

Factor	χ^2	df	P	ε^2
Scale of organisational innovativeness	0.5260	1	0.468	0.01315
In-house market research	4.1308	1	0.042	0.04918
Customer suggestions	4.4277	1	0.035	0.05271
Supplier proposals	0.0596	1	0.807	0.00071
Management ideas	0.0694	1	0.792	0.000826
Technologists' ideas	0.9560	1	0.328	0.01138
Machine operators' ideas	0.4757	1	0.490	0.00566
Sales force ideas	4.2707	1	0.039	0.05084
Internal R&D activities	9.1375	1	0.003	0.10878
Consulting firms	2.4732	1	0.116	0.02944
Business support institutions	4.0193	1	0.045	0.04785

Cont. table 3.

Open sources	1.4529	1	0.228	0.01730
Purchase of IP / licences	3.7855	1	0.052	0.04506
Scientific research	6.3254	1	0.012	0.07530
Sector events	0.1985	1	0.656	0.00236
Imitation	0.3097	1	0.578	0.00369

Source: own elaboration.

Table 3 shows that the benefits of innovation are linked to the sources of innovation, with the ability to independently create innovations and cooperation with entities capable of conducting research and implementation work (e.g. scientific organizations) constituting a significant added value for achieving benefits or the innovative development of the company.

5.3. Importance of external and internal sources of innovation

The innovations implemented in the surveyed firms differed noticeably in terms of their sources (Figure 5). Among companies that introduced innovations, managerial ideas stood out most prominently: 36.67% of respondents rated them as highly important, and an additional 10.83% as very highly important. Technologists' ideas were also evaluated strongly, with 33.33% of respondents assigning them high importance and 8.33% very high importance. Industrial events received 24.17% indications of high importance and 7.50% of very high importance, while imitation was rated as highly important by 24.17% of firms and as very highly important by 1.67%.

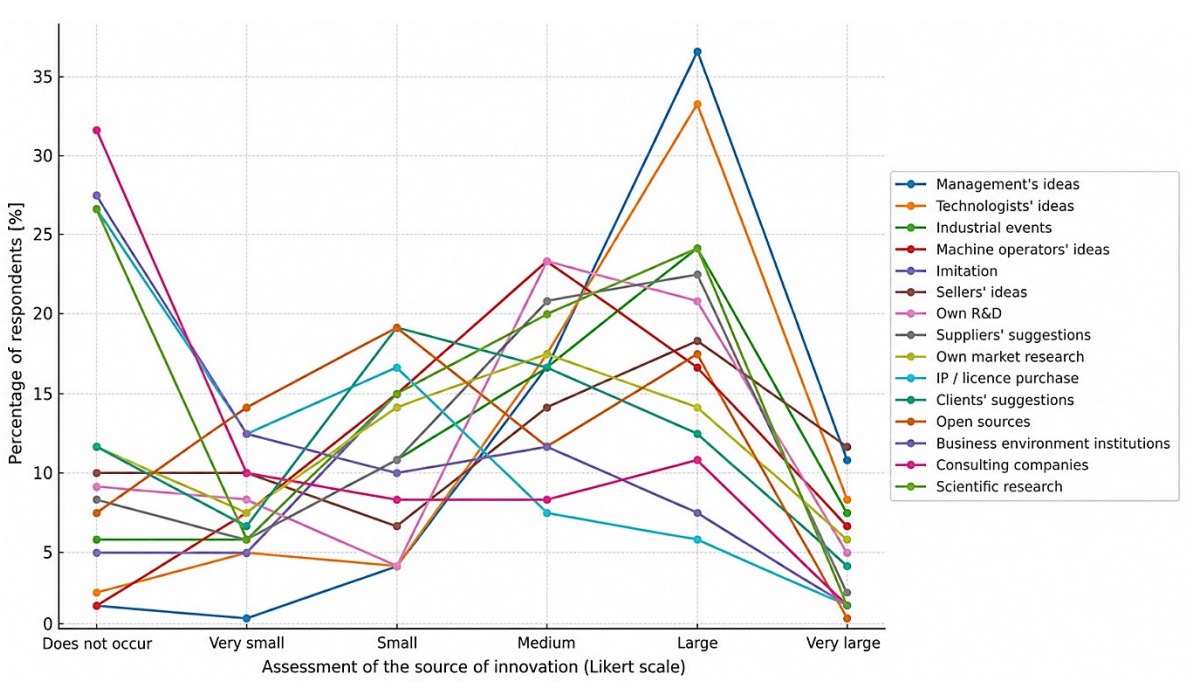

Figure 5. Full distribution of responses in percentage scale on the importance of internal and external sources of innovation, including cases where a given source does not occur.

Source: own elaboration.

The importance of ideas generated within the organisation was rated as high by 18.33% of firms and as very high by 11.67%, while ideas originating from machine operators were rated as highly important by 16.67% of respondents and as very highly important by 6.67%. Internal R&D activities were assessed as highly important by 20.83% of firms and as very highly important by 5.00%. Supplier suggestions received 22.50% high-importance ratings and 2.50% very-high-importance ratings, whereas in-house market research was rated as highly important by 14.17% of firms and as very highly important by 5.83%.

Less significant innovation sources included customer suggestions (12.50% high importance, 4.17% very high importance), open knowledge sources (17.50% and 0.83%), scientific research (24.17% and 1.67%), business support institutions (7.50% and 1.67%), consulting firms (10.83% and 1.67%) and the purchase of intellectual property rights or licences (5.83% and 1.67%).

Overall, internal resources were most frequently identified by firms as sources of high or very high importance - particularly managerial and technologists' ideas, internal R&D activities and supplier suggestions. External sources of knowledge, including even business support institutions and research conducted by academic bodies, were more often positioned outside the firms' core innovation sources. Exceptions included industrial events, open-source knowledge and imitation, which reached importance levels comparable to some internal resources.

Subsequently, the Kruskal–Wallis test was applied to examine whether the availability of external resources differentiated firms that reported benefits from innovation development and firms that had implemented any of the four primary innovation types (Table 4).

Table 4.
Differences between firms that achieved measurable benefits from innovation development and those that did not, in terms of the availability of external resource sources

Availability factor	**χ^2**	**df**	**P**	**ε^2**
Availability – material resources	0.921	1	0.337	0.01097
Availability – financial resources	2.471	1	0.116	0.02941
Availability – human resources	0.242	1	0.623	0.00288
Availability – intellectual resources	0.404	1	0.525	0.00481

Source: own elaboration.

No statistically significant differences between groups were observed regarding access to any external resources in the case of product innovations ($p > 0.223$), process innovations ($p > 0.0684$) or marketing innovations ($p > 0.067$). A statistically significant between-group difference appeared only for the availability of external material resources between firms that implemented organisational innovations and those that did not ($p = 0.015$). Importantly, the availability of external resources did not significantly distinguish firms that reported benefits from innovation development from those that did not ($p > 0.0116$), suggesting that external resource availability did not translate into a higher propensity to innovate.

5.4. Importance of material and intangible resources

Among the 85 firms that implemented innovations during the past three years, material resources (movable and immovable assets) were absent or of no importance in 5.83% of cases (5 firms), of high importance in 16.67% (14 firms) and of very high importance in another 16.67% (14 firms. Financial resources were absent or of no importance for 0.83% of firms (one response), highly important for 26.67% (23) and very highly important for 14.17% (12). Human resources were absent or of no importance for 0.83% of firms (1), of high importance for 20.00% (17) and of very high importance for 29.17% (25). Organisational practices were absent or unimportant in 0.83% of firms (1), of high importance in 19.17% (16) and of very high importance in 21.67% (18). Relational resources were absent or unimportant in 2.50% of firms (2), of high importance in 29.17% (25) and of very high importance in 18.33% (15). Intellectual resources were absent or unimportant in 0.83% of firms (1), of high importance in 25.00% (21) and of very high importance in 23.33% (20).

As with innovation sources, the descriptive analysis already reveals a clear dominance of intangible resources - particularly human, relational and intellectual - over material and financial resources, although the latter also played a relevant role in the assessment of offset printing firms. These findings indicate that, in the perception of managers, it is people and the associated intangible capabilities rather than financial inputs that determine the success of innovation implementation.

Statistically significant differences ($p < 0.05$) between firms that achieved measurable benefits from innovation development and those that did not were identified for material resources ($p = 0.039$), financial resources ($p = 0.034$), human resources ($p = 0.010$) and intellectual resources ($p = 0.032$), whereas differences in the importance of organisational practices ($p = 0.176$) and relational resources ($p = 0.603$) were not statistically significant.

Average values further indicate that across all resource categories, importance ratings were higher among firms that achieved measurable benefits from innovation development (2.66-3.54) than in the group that did not (1.87-2.87). The largest difference concerned human resources (3.54 vs. 2.87), while the smallest occurred for relational resources (2.89 vs. 2.87).

The greater importance of intangible resources is further supported by differences in the presence of relational resources (absence, current presence or expected future presence as ordinal characteristics) in achieving innovation-related benefits, tested using the Kruskal-Wallis test (Table 5). Firms that achieved measurable benefits from innovation development differed significantly from those that did not in terms of the importance of relationships with business support institutions ($p = 0.007$), research organisations ($p = 0.033$) and universities ($p < 0.001$). Differences in relationships with SMEs ($p = 0.120$), large enterprises ($p = 0.217$) and public organisations ($p = 0.079$) were not statistically significant.

Table 5.
Differences between firms that achieved measurable benefits from innovation development and those that did not, in terms of the availability of external relational resources

Relational factor	χ^2	df	P	ε^2
Relations – SMEs	2.41	1	0.120	0.0287
Relations – large firms	1.53	1	0.217	0.0182
Relations – business support institutions	7.20	1	0.007	0.0857
Relations – research organisations	4.55	1	0.033	0.0541
Relations – universities	12.12	1	< 0.001	0.1443
Relations – public organisations	3.09	1	0.079	0.0368

Source: own elaboration.

Table 5 shows that benefits are generally more strongly visible in case of relations with entities that can conduct or significantly facilitate company's own R&D, rather than provide ready-made innovative solutions.

5.5. Resources as individual determinants of specific types of innovation

To conduct a more detailed examination of the above factors within the subgroup of firms that implemented innovations (n = 85), the Kruskal–Wallis test was applied. The results indicate that structural characteristics most directly linked to firm resources (number of employees, number of machines, dominant print formats) do not differentiate firms that implemented product innovations from other innovative offset printing firms ($p > 0.218$). Similarly, these characteristics were not significant for process innovations ($p > 0.074$) or organisational innovations ($p > 0.127$). In the case of marketing innovations, however, the number of machines proved statistically significant ($p = 0.026$). It should be noted that, due to the widespread adoption of service-oriented business models among manufacturers of offset printing equipment (Salwin, 2020), this factor reflects external resources no less than internal ones.

In the Kruskal–Wallis test examining differences in the perceived importance of resources between firms that implemented product innovations and those that did not, statistically significant differences concerned the importance of customer suggestions ($p = 0.005$), open-source innovation inputs ($p = 0.010$) and the acquisition of external intellectual property or licences ($p = 0.008$).

For process innovations, the differentiating factors were the importance assigned to the inventiveness of technologists ($p = 0.013$), the inventiveness of sales personnel ($p = 0.008$), the purchase of intellectual property or licences ($p = 0.034$), sector events ($p = 0.030$) and imitation ($p = 0.025$).

Firms that implemented marketing innovations differed significantly from others in their declared importance of: in-house market research ($p = 0.005$), technologists' ideas ($p = 0.004$), consulting firms ($p < 0.001$), business support institutions ($p = 0.009$), open-source knowledge ($p = 0.005$), the purchase of intellectual property rights or licences ($p = 0.005$) and scientific research ($p = 0.040$).

These factors are summarised in Table 6. The results indicate that internal resources play a significant role across all types of innovations, while the importance of external factors increases progressively - from organisational innovations, through process and product innovations, to marketing innovations. Moreover, intangible resources become particularly important as drivers of product and process innovations.

Table 6.
Resource factors associated with the occurrence of specific types of innovation, categorised according to the theoretical classification.

Innovation type	Internal resources – material	Internal resources – intangible	External resources – intangible
Product innovation	–	–	Customer suggestions; open-source innovation inputs; acquisition of external intellectual property or licences
Process innovation	–	Inventiveness of technologists; inventiveness of sales personel	Acquisition of intellectual property or licences; sector events; imitation
Organisational innovation	–	–	–
Marketing innovation	Number of machines	In-house market research; technologists' ideas	Consulting firms; business support institutions; open-source knowledge; acquisition of intellectual property or licences; scientific research

Source: own elaboration.

Table 6 shows that the types of innovations are differentiated to a greater extent by external resources than by internal resources.

6. Discussion

As the results indicate, packaging companies proved to be more innovative. This finding should be interpreted in light of three key contextual characteristics of these firms.

First, packaging constitutes one of the most prospective segments of the printing industry. Unlike traditional offset print products (books, newspapers, printed forms, leaflets, posters, or other printed materials), whose functions may be partly or wholly displaced by digital technologies, packaging performs an indispensable economic function. Its role is not limited to the transmission of information but primarily involves the protection, containment, storage, transport, and distribution of physical goods. This applies in particular to food packaging, whose production remains non-substitutable so far (Pascal et al., 2022). Against the background of the European printing industry as a whole, packaging represents one of the main areas of growth, whereas the overall value of the European print market is characterized by lower growth dynamics and less favorable growth forecasts than the packaging sector. This is

primarily associated with the intensive development of e-commerce, which increases demand for packaging, ranging from simple corrugated cardboard boxes to complex, high-value products (Horváth, Koltai, Orgován, 2025). Consequently, the allocation of long-term investment and the strategic orientation of production toward packaging may be regarded as a rational development strategy, and such a strategy is closely linked to innovation.

Second, packaging companies primarily serve manufacturers of consumer goods, for whom packaging constitutes an important instrument of market competition, marketing differentiation, and regulatory compliance. This generates continuous pressure to modify packaging design, functionality, print quality, environmental performance, and protective features. In contrast to more traditional segments of the printing industry, demand for innovation in packaging is therefore generated directly by industrial customers (Beckeman, Olsson, 2010). This interpretation is partly supported by the observed significance of customer suggestions as a factor associated with marketing and product innovations, but not with process or organizational innovations.

Third, the higher innovativeness of packaging firms may also result from the relatively greater capital intensity and technological complexity of packaging production, which requires a specific and more advanced machinery base. The study showed that the number of machines is among the strongest factors differentiating innovative firms from non-innovative ones. Moreover, it correlates with the degree of novelty of product and process innovations, that is, with technological innovations. Packaging production, particularly in B1 and B0 formats, requires more advanced equipment than many other segments of the printing industry. Firms possessing such resources therefore have, under the conditions examined in this study, a greater capacity to implement new technological solutions.

The last of these interpretations provides a point of departure for explaining why medium-sized enterprises exhibit a statistically higher level of innovation implementation. The relationship between innovativeness and medium firm size may be interpreted in terms of the greater resources available to larger firms, which are necessary for the implementation of innovation (Gachmann, Kataishi, 2025). This assumption is related to the debate over whether innovativeness is a direct function of firm size, meaning that after a certain threshold it increases proportionally with firm size rather than more rapidly (Symeonidis, 1996), or whether certain innovations generate effects proportional to the scale of production, making them economically rational only in larger firms and thereby producing economies of scale (Cohen, Klepper, 1996; Iammarino, McCann, 2006; Archibugi, Evangelista, Simonetti, 1995). Small firms tend to exhibit above-average innovativeness only under conditions of clear market dominance by large firms (Gachmann, Kataishi, 2025; Acs, Audretsch, 1988), which is not the case in the present study. Since the sample consisted predominantly of small and medium-sized enterprises, the greater share of medium-sized firms in the innovative group may be interpreted as an outcome of the positive relationship between innovativeness and firm size.

At the same time, innovativeness is higher among firms oriented toward international markets. This may be explained in two main ways.

First, exporting firms are subject to substantially stronger competitive pressure. In local markets, a firm competes with a limited number of entities, whereas in international markets it must confront larger producers from multiple countries. Under such conditions, the development of competitive advantage requires continuous improvement through innovation (Onodera, 2008).

Second, firms present in foreign markets gain access to broader knowledge resources. Contact with foreign customers, suppliers, competitors, and business partners increases the number of sources of information on new technologies, market trends, and organizational solutions, in line with the mechanism of "learning by exporting" (Freixanet, Federo, 2023; Rafique, Abbas, 2025). This mechanism is relatively strong among small and medium-sized enterprises (Almeer, 2026), especially when it is linked to their digital transformation (Said, Soi, 2025).

The study confirms the prevailing view in the literature that innovation depends on both internal and external resources. However, the interpretation proposed by Nguyen and Minh (Nguyen, 2023) - that external resources dominate in an open, innovation-driven economy - appears premature. The analysis demonstrates that the offset printing sector is an area of intensive innovation activity, driven by strong market-shaping mechanisms (regulatory pressure, internal and external competitive pressures), which is reflected in the high prevalence of all types of innovations among the respondents. In this sector, external determinants of innovativeness did not dominate; moreover, the availability of external material, financial, human or intellectual resources generally did not differentiate firms that achieved innovation-related benefits from those that did not.

These findings align with the observations of Wu et al. (Wu, 2022) and Zhu et al. (Zhu, 2025), who argue that internal intangible resources are more important than external and material resources. They also support the conclusions of Mališić et al. (Mališić, 2025) regarding the role of human resource management and absorptive capacity: the highest-rated sources of innovation included managerial ideas, technologists' ideas and internal R&D activities, indicating the critical role of internal organisational processes and likely reflecting an innovation-oriented organisational culture.

Partial support was found for the observation by Phung et al. (Phung, 2021) that the relevance of external resources increases alongside the strength of the institutional environment. In marketing-related offset innovations - where business support institutions, scientific research and consulting were more frequently involved - external factors were more important than in other innovation types. However, there was no full confirmation of the claim that innovativeness is determined exclusively by external sources, as process, product and organisational innovations remained predominantly driven by internal factors - most of them directly linked to the firm's human resources.

Similarly, although Keil et al. (Sesli, 2023) emphasise the role of broad networking, the analysed sector did not exhibit a dominance of network-related effects over those stemming from internal innovation activities. The threshold effect proposed by Carboni and Medda (Cecere, 2014) concerning the diminishing returns of external resources found direct support in this study. Given that no clear differences in access to external resources were found between firms that did and did not achieve innovation-related benefits, it follows that access alone - without the capability to utilise it - is insufficient for innovation development. Considering that firms also differ in their perceived benefits from innovation development, it can be assumed that the propensity to innovate - operating alongside innovative capability - acts as a moderating factor (Stanisławski, 2022).

7. Conclusions

The study confirmed that the implementation of innovations depends on both internal and external resources, manifested in structural characteristics as well as in the relationships between the degree of innovativeness, novelty and resources. Accordingly, **Hypothesis H1** was positively verified.

Structural characteristics (operational market, number of employees, dominant sector, number of machines and dominant print format) significantly distinguished firms that implemented innovations from those that did not. The degree of novelty of innovations was also associated with specific resources, differentiated across innovation types.

The study further demonstrated that internal sources of innovation generally carried more weight than external ones, leading to the positive verification of **Hypothesis H2**. Innovative firms in the offset printing sector more frequently identified and highly assessed internal sources - such as managerial ideas, technologists' ideas and internal R&D activities - than external ones. At the same time, different innovation types varied in the relevance of internal and external resources and in their links with the degree of novelty (e.g., marketing innovations were more strongly associated with external factors, while organisational innovations were shaped exclusively by internal structural characteristics). The availability of external resources generally did not significantly differentiate firms that reported innovation-related benefits, indicating that external resources alone are insufficient drivers of innovation development.

With respect to **Hypothesis H3**, the findings showed that intangible resources - particularly human, relational and intellectual resources - were more important than material resources. This hypothesis was therefore also positively verified. Firms more often pointed to intangible resources as crucial for innovation development, and the perceived importance of both material and intangible resources significantly differed between firms that achieved and those that did

not achieve measurable innovation-related benefits. Significant differences were found for material, financial, human and intellectual resources.

Innovation types differed in their determinants, confirming **Hypothesis H4**. Structural factors did not differentiate all firms; they were more relevant for marketing innovations (number of machines), while for other types of the effects were not statistically significant. Only when considered as independent determinants of innovativeness can these factors be treated as relevant across innovation types. Both internal and external sources were significantly associated with innovation types and their degree of novelty, though the relevance varied by innovation type. Different relational resources favoured different types of innovations, indicating variation in the importance of intangible and external resources.

Overall, the Polish offset printing sector is highly innovative. Most firms implemented innovations of various types, drawing on diverse sources reflected in both internal and external resources. Possessing specific internal resources - particularly intangible ones - is fundamental. These resources are more important than external ones, which are readily accessible but not always convertible into innovation-related benefits.

Intangible resources, especially human and intellectual resources, are essential for innovation development because they enable the effective use of material resources and determine the capacity to leverage external resources. **For innovation development (which depends on both the propensity and capability to innovate) the presence of core resources is necessary to recognise the need for innovation (and the associated benefits) and to implement innovation strategies.**

Considering the findings, innovation development based solely on the transfer of financial means for accessing external resources appears unfeasible. The primary drivers of innovation are internally generated, particularly those rooted in the inventiveness of employees: managers who shape an innovation-oriented organisational culture and in-house specialists, including technologists. These human-centred intangible resources constitute the foundational condition for achieving sustainable innovation outcomes in the offset printing sector.

8. Managerial Implications

Offset printing companies operate in an environment characterised by rapid technological change, intensifying competitive pressure and increasing regulatory demands associated with the green transformation of the printing industry. Competition arises not only from other offset printers but also from the expanding digital printing market, whose technological advantages - particularly at low volumes - force offset printers to implement continuous innovation. In this context, sustainable competitiveness requires adopting new business models grounded in service-oriented rather than product-centric value propositions. This shift necessitates the

ongoing implementation of multiple innovation types - process, product, organisational and marketing - which were shown in this study to be increasingly widespread across the sector.

Managers should translate open innovation, Environmental, Social, and Governance (ESG) foresight and ESG competence development into specific actions concerning barriers identified in the study. To reduce the high costs of product and process innovation associated with environmental requirements, firms should intensify cooperation with suppliers, and research organisations in order to share knowledge, testing infrastructure and other sources of developmental costs. To cope with short regulatory implementation deadlines in the European Union, managers should use ESG monitoring and foresight mechanisms that enable the early identification of upcoming environmental requirements and allow sufficient time for adaptation. Given the limited financial and human resources characteristic of many offset printing firms, ESG-related investments should be prioritised according to their expected operational and market benefits, while external support programmes and industry partnerships should be used to complement internal capabilities. Employee resistance to change should be addressed through continuous training, cross-functional involvement in innovation projects and transparent communication of the business and environmental benefits of new solutions. Such measures can strengthen ability to implement sustainability-oriented innovations while maintaining competitiveness in a rapidly changing market environment.

For managers, the findings highlight that the effectiveness of innovation strategies hinges on a targeted and rational allocation of resources. In an environment where external resources - knowledge, technologies, networks or market information - are relatively easily accessible, competitive advantage stems not from access itself but from the capability to absorb, interpret and utilise these resources. This capability is strongly rooted in internal intangible assets: human capital, managerial and technological expertise, organisational culture and internally generated intellectual resources.

Managers should therefore prioritise the development of internal absorptive capacity, understood as the ability to recognise the need for innovation, integrate new knowledge, and apply it to commercial ends. Strengthening internal knowledge creation processes - through training, recruitment of technologically skilled staff, cross-functional collaboration and internal R&D - should be treated as a strategic investment, not a cost. The study clearly indicates that firms with strong internal creative capabilities (especially managerial and technological ideation) are significantly more likely to achieve measurable benefits from innovation.

At the same time, relational assets - collaboration with research organisations, universities, business support institutions and specialised suppliers - remain essential enablers. However, these relationships create value only when the firm possesses the internal competencies necessary to transform them into innovative outcomes. Thus, managers should design relational strategies not as substitutes for internal capacity, but as complementary mechanisms that extend the firm’s innovation potential.

To build a lasting competitive advantage, offset printing companies must adopt strategies that:

- systematically strengthen intangible assets, particularly human, relational and intellectual resources,
- embed innovation into organisational routines, enabling continuous recombination and improvement of products, processes and business models,
- leverage external resources selectively, prioritising those that align with the firm's internal capabilities and strategic direction,
- develop service-oriented and digital business models that utilise both material (machines, formats, production capabilities) and intangible assets to deliver higher customer value,
- cultivate an organisational culture that rewards creativity, experimentation and learning, particularly among managers and technologists, who play a central role in generating innovative ideas.

Managers who fail to recognise the strategic importance of intangible resources and rely solely on external inputs - such as the purchase of machines, technologies or licences - risk limiting their company's innovation potential. In highly dynamic market conditions, such firms are unlikely to fully benefit from innovation-driven development and may face substantial long-term disadvantages.

In contrast, firms that leverage their internal creative capacity, supported but not replaced by external collaborations and material assets, are best positioned to adapt, compete and thrive within the transforming global printing industry.

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STRATEGIC PROJECT MANAGEMENT IN CENTRAL GOVERNMENT ADMINISTRATION: DILEMMAS OF INSTITUTIONALISATION

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Purpose: The article identifies the key institutional dilemmas that emerged during the implementation of the project-based approach in Polish central government administration and draws lessons relevant to the design of future mechanisms for implementing state strategy.
Design/methodology/approach: The article takes the form of a qualitative case study of the Strategic Project Monitoring System (*System Monitorowania Projektów Strategicznych*, SMPS), implemented between 2015 and 2023, and contributes to the tradition of practice-based/practice-informed research. The analysis draws on six years of expert-level professional experience in the development and implementation of the SMPS, a review of the relevant literature, primary source documents, reports of the Supreme Audit Office, and an unpublished internal research report produced by the Government Project Monitoring Office. The interpretive perspective incorporates Flyvbjerg's phronetic approach to organisational research.
Findings: The analysis identifies four categories of institutional dilemmas: the role of strategic documents in day-to-day state governance, including the functioning of the strategic projects portfolio; the definition of projects and the question of who implements them; the ambiguity of the concept of programme in public administration; and the conditions for meaningful implementation of the project-based approach. The absence of shared conceptual and organisational resolutions impedes the use of project monitoring as an effective management instrument.
Research limitations/implications: The findings reflect a single national case and the author's interpretive perspective as a reflective practitioner, mitigated through data triangulation.
Practical implications: Before formalising the project-based approach, administrators should reflect on the key conceptual questions regarding projects, programmes, and portfolios. Clear resolutions are desirable but not always achievable; what matters is awareness of these dilemmas. The strategic projects portfolio should be designed as a dynamic management instrument, not merely an annex to a strategic document.
Originality/value: The article offers a practice-informed institutional analysis of a concluded attempt to institutionalise the project-based approach in central government administration, providing a knowledge base for subsequent attempts at metagovernance of state strategy implementation. It is addressed to researchers in public administration and to practitioners responsible for designing strategic management systems in government.
Keywords: project-based approach, strategic project management, public administration, institutionalisation, metagovernance.
Category of the paper: Case study / Viewpoint.

1. Introduction[1]

An important element of strategic state governance is meta-governance, understood as "an attempt to modify the institutional conditions that provide the framework for addressing particular types of social problems, undertaken in situations where existing conditions prove inadequate or dysfunctional" (Strumińska-Kutra, 2012). Well-designed institutions exert a decisive influence on the development of societies (Acemoglu, Robinson, 2014). In the case of Poland, however, analysts have identified "the limited significance of innovation in the management of public organisations, which constrains processes of change and development" (Wiatrak, 2017, p. 233). One such innovation may be the wider adoption of the project-based approach in public administration (Wiatrak, 2017, p. 236). In various countries, this approach has been associated both with reforms inspired by New Public Management – emphasising efficiency and accountability for results – and with later conceptions of good governance, which stress coordination, cooperation, and the capacity of the state to address complex problems. It is, on the one hand, a technique for organising work and, on the other, an element of broader institutional design: the creation of procedures, structures, roles, coordination mechanisms, and learning processes that enable the implementation of complex public interventions.

The project-based approach is reflected in Polish strategic documents. For example, the *National Development Strategy to 2020*, published in 2012, identified "increasing the effectiveness of public institutions" as one of its priorities, to be pursued through "the introduction of a managerial model of public governance, characterised inter alia by a citizen-centred orientation" and "a focus on the control of outcomes rather than procedures" (Strategia rozwoju kraju 2020, 2012, p. 34). The *Strategy for Responsible Development* (SRD), adopted on 14 February 2017 and superseding the aforementioned document, linked state efficiency to, among other things, "increasing the effectiveness of public institutions" (Strategia na rzecz Odpowiedzialnego Rozwoju, 2017, p. 225)[2]. Among the instruments of implementation, the strategy listed project management, the building of inter-ministerial thematic teams, management by objectives, and e-government solutions. The SRD was to be "implemented using the project-based approach" characteristic of contemporary management concepts (Strategia na rzecz Odpowiedzialnego Rozwoju, 2017, p. 385). One of its aims was to move away from public policy conducted primarily through the successive enactment of legal regulations (cf. Zybała, 2012, p. 355).

[1] AI-assisted language correction and editing tools were used solely for linguistic correction and editing in the final stages of preparing this article. The article was translated into English with the assistance of AI tools.
[2] The SRD links managerial competence development mainly to the private sector.

The Ministry of Funds and Regional Policy (*Ministerstwo Funduszy i Polityki Regionalnej*, MFiPR) is currently developing a new medium-term national development strategy[3]. Regardless of any substantive assessment of that document, the effective implementation of the concepts it contains should be aided by drawing on experience gained during the implementation of the SRD. The continuity of administrative work is partly ensured by staff continuity within the ministry responsible for regional development. It may be assumed, however, that in central government offices – including the Chancellery of the Prime Minister (*Kancelaria Prezesa Rady Ministrów*, KPRM) – the personnel continuity of teams responsible for the operational monitoring of projects arising from the SRD is limited (cf. Zybała, 2012, p. 211). Meanwhile, the MFiPR website states that the document under preparation includes an action plan together with key projects to be implemented in the years 2026-2029 (Ministerstwo Funduszy i Polityki Regionalnej, 2026). Alongside the analytical, strategic, and editorial work, central government administration also carries out numerous projects on a day-to-day basis, for which the war in Ukraine, international security instability, and initiatives such as the National Recovery and Resilience Plan (*Krajowy Plan Odbudowy*, KPO) and SAFE constitute additional points of reference (Ziemacki, 2021).

The question therefore arises of what the institutional foundations for implementing projects in central government administration are, and whether the lessons learned from successive implementations are being collected, analysed, and applied in the design of new development strategies. Despite the presence of the project-based approach in the state's strategic documents, the mechanisms that support or undermine the implementation of strategic projects in government administration remain relatively poorly understood. This is particularly significant when one considers that project management – owing to its dynamic and diverse development – is sometimes described as a field that is "unformed and disorganised", still "in an early stage of development (*in statu nascendi*)", in which "even the most basic assumptions and principles (…) are not uniform" (Lichtarski, 2016). As a result, paradoxes and antinomies form an inherent part of the project-based approach, embedded, as it were, in the very nature of this field (Lichtarski, 2016). The aim of this article is therefore to review and systematise the experience of government administration between 2015 and 2023 with regard to the project-based implementation of state strategy[4]. On that basis, it asks what the key dilemmas of project management are and how they manifested themselves in a concluded attempt at implementation, the Strategic Project Monitoring System (*System Monitorowania Projektów Strategicznych*, SMPS), so as to draw lessons for the government administration responsible for implementing new strategic documents.

[3] In late 2024, the government announced plans to adopt the medium-term national development strategy by mid-2025. (TVP Kraków, 2024).

[4] The period under analysis begins in 2015 because the preparatory work on the SRD that year, including the call for project proposals submitted by ministries (cf. Section 4.2), already shaped the institutional logic within which the SMPS subsequently operated.

The article demonstrates that the experience of SMPS makes it possible to identify the fundamental challenges of institutionalising the project-based approach in government administration. The problem is not reducible solely to the need for stronger formal grounding of the system, as postulated by the Supreme Audit Office (Informacja o wynikach kontroli SMPS, 2022). Equally significant are the unresolved institutional dilemmas concerning the relationships between strategy, portfolio, programme, and project; between political and administrative accountability; and between mechanisms of organisational learning. The experience of the SMPS should therefore be treated not merely as a concluded chapter of the previous government's activities, but also as a resource of knowledge for subsequent attempts at meta-governance of state strategy implementation.

The precise questions raised in this article – what constitutes a strategy, what constitutes a project, what constitutes a programme, and what does the implementation of the project-based approach actually require – may appear elementary. Returning to them may at times give the impression of redundancy, as though one were explaining concepts taken for granted. In the practice of public management, however, overlooking them leads to significant misunderstandings. The analysis conducted in this article aims to expose the hidden assumptions and ambiguities that shape administrative practice. Understood in this way, the redundancy of knowledge – in Nonaka and Takeuchi's sense of intentional informational overlap – is not superfluous repetition, but a precondition for organisational learning and a source of potential institutional innovation (Nonaka, Takeuchi, 2000, p. 107).

2. Research Methodology

Henry Mintzberg described management as a process of "collective learning by managers" (Mintzberg et al., 1998, cited in Jemielniak, Koźmiński, 2012, p. 86). It is likewise emphasised within public management that "the sphere of producing feedback knowledge on the outcomes of public actions is key to the effectiveness of policies" (Zybała, 2012, p. 355). The article was produced within the field of political science and public administration, in the context of institutional studies on public management, and contributes to the tradition of practice-based/practice-informed recommendations (Weber et al., 2014). It constitutes a record, of sorts, of the lessons learned from the process of implementing the project-based approach in administration between 2015 and 2023. The point of departure for the reflections undertaken here was the assumption that, since governance bears the characteristics of an experiment, a key element of that process should be reflection on its course and the capacity to undertake

corrective action where necessary (Strumińska-Kutra, 2012)[5]. In the case under examination, the reference point for the experiment thus understood was the concept of project, programme, and portfolio management. The accumulated experience positions the article at the intersection of institutional research and practical reflection, incorporating stakeholder knowledge in the diagnosis of organisational problems (Strumińska-Kutra, 2012). The perspective adopted is interpretive in character: its cognitive value lies in the possibility of verbalising experience and formulating potential recommendations that may serve as a starting point for further research in the field of metagovernance (Strumińska-Kutra, 2012).

An important theoretical reference for the reflections undertaken here is also the Aristotelian concept of *phronesis*, as adapted to the study of public management by Bent Flyvbjerg (Flyvbjerg, 2006). This approach emphasises the significance of practical wisdom, contextuality, and the analysis of power relations and values in decision-making processes. It enables the examined reality to be viewed not only through the lens of formal procedures and structures, but also through that of practical judgements, values, power relations, and the institutional context within which decisions were made.

The article takes the form of a qualitative case study. The analysis draws on the interpretation of practical experience, primary source materials, and secondary data, conducted iteratively using an interpretive approach. The identification of the dilemmas presented in this article was grounded in, among other things, six years of expert-level professional experience (2016-2022) in the development and implementation of the Strategic Project Monitoring System (SMPS).

Issues were treated as analytically significant if they recurred across those years of professional experience, remained conceptually unresolved despite institutional attempts to address them, and found independent confirmation in the documents examined in this article. Episodic or idiosyncratic difficulties were not. The conclusions formulated are the result of accumulated observations concerning the functioning of public institutions, recurring operational challenges, and informal organisational dynamics that frequently fall outside the scope of formal analyses. In this sense, the article draws on the perspective of the reflective practitioner (Schön, 1983), in which professional experience becomes a source of analytical knowledge and a basis for formulating recommendations. The present text goes beyond the level of individual reflection, however, in that it focuses – drawing on the relevant literature – on institutional processes and the formulation of systemic recommendations.

The analysis also draws on empirical materials that have hitherto featured only to a limited extent in the academic literature. These include a report of the Supreme Audit Office (*Najwyższa Izba Kontroli*, NIK) and an unpublished internal research report prepared by the Government Project Monitoring Office (*Rządowe Biuro Monitorowania Projektów*, RBMP;

[5] "In this process, the key capacity proves to be the ability to reflect on the course of the experiment that is the implementation of designed solutions, and the ability to undertake corrective action when planned activities fail to produce the intended effects. Changes occurring in administration constitute precisely such an experiment".

KPRM, 2023)[6]. The study, conducted in 2023, aimed to diagnose the state of implementation of the system under examination within government administration. The system was analysed across six functional areas (Council, people, guidelines, organisation, portfolio, system) using a triangulation of research methods encompassing data analysis, survey questionnaire (N = 154, comprising 76.6% Project Leaders, 12.3% Programme Managers, and 11.1% representatives of Project Monitoring Offices), and four focus group interviews.[7] The focus groups were conducted between 10 and 22 August 2023, in two-hour sessions with a total of 17 representatives – one from each Project Monitoring Office[8] – using a standardised interview scenario. The level of System advancement was measured using a composite index based on twelve factual questions concerning strategic projects, grouped into key and important factors (e.g., whether an up-to-date budget, product list, and goal list had been defined for a given project), which together produced the 24-point scale reported in Section 3. The findings made it possible to identify both achievements and gaps in the implementation of the system, as well as to determine the directions and needs for its further development.

The perspective adopted in the article is consistent with the postulate of increasing the weight accorded to qualitative research in the analysis of public management processes (Hendren et al., 2022). At the same time, it entails certain limitations, chief among them the risk of subjectivity arising from participation in the processes under examination. This risk was mitigated through the application of data source triangulation, consisting in the cross-referencing of observations with the analysis of primary source documents and a review of the relevant literature. The aim of the article is not to present a universal model for implementing the project-based approach in administration, but to identify the dilemmas that emerged in a specific institutional case. The conclusions are therefore analytical and recommendation-oriented, and may serve as a starting point for further comparative research and the design of subsequent institutional solutions.

[6] The report was obtained on 24 March 2025 in response to a request submitted to the KPRM under the procedure for access to public information.

[7] The design of the expert analyses, the survey questionnaire, and the interview scenario was supported by the Working Group for Expert Support in the Development of the Strategic Project Monitoring System. The composition of the Working Group, listed in the annex to the research report, was as follows: Chair of the Working Group: Błażej Olek, PhD (Government Analysis Centre, KPRM); Mateusz Juchniewicz, Habilitated PhD, Professor of SGH Warsaw School of Economics; Bogdan Lent, Habilitated PhD, Professor of Bydgoszcz University of Science and Technology; Jacek Strojny, Habilitated PhD, Professor of Rzeszów University of Technology; Paweł Wyrozębski, Habilitated PhD, Professor of SGH Warsaw School of Economics; Piotr Charchuta (RBMP, KPRM); Monika Malocco (RBMP, KPRM); Tomasz Ugryn (RBMP, KPRM).

[8] The KPRM and one ministry without currently registered strategic projects were excluded from this part of the study.

3. The Strategic Project Monitoring System

The Strategic Project Monitoring System represented an attempt to institutionalise the project-based approach at the centre of government administration. Its emergence should be understood both as a response to the earlier implementation deficits of Polish strategic documents and as part of the projectification of contemporary public management, also referred to as the development of the project economy (Midler, 1995). Industry reports emphasise that the capacity for project management is becoming one of the conditions for the effective achievement of strategic objectives, and that project competences are counted among the core skills of contemporary organisations (Nieto-Rodriguez, 2021). Projectification is extensively discussed both in the academic literature and in practitioner-oriented publications (Jacobsson, Jałocha, 2021).

The implementation dimension of the SRD was particularly significant given the previously superficial treatment of implementation in Polish strategic documents (cf. Płoskonka et al., 2012, p. 63). Earlier diagnoses had pointed to a "weakness in the implementation of programme documents" and inadequate inter-ministerial coordination (Grosse, 2006). The ex ante evaluators of both the Efficient State Strategy and the Medium-Term National Development Strategy similarly criticised the lack of detail given to implementation instruments and implementing bodies (Raport ex ante SOR, 2016). In the language of administrative practitioners, the SRD's aim was to break with the practice of adopting documents dismissed as "fiction" or "shelf-warmers", replacing it with a culture of "delivering commitments" – finalising projects and achieving assumed indicators (Kędzierski, 2022, p. 5). As the Supreme Audit Office later noted, prior to 2017 strategic projects had typically been implemented without an organised management and monitoring system or integrated management information enabling the optimisation of resources (Informacja o wynikach kontroli SMPS, 2022; cf. Zybała, 2012, pp. 259-260).

The provisions of the SRD concerning project management corresponded to the conclusions of an administrative capacity-building project conducted by the Head of the Civil Service in 2011-2015. A 2015 PwC report summarising this project found that, among the 168 participating offices, "no systemic activities aimed at professionalising project management" had been observed (Procesy, cele, kompetencje…, 2015, pp. 72, 104-105). The report recommended adopting established project management methodologies and systematically deepening staff knowledge in the field (Procesy, cele, kompetencje…, 2015, p. 104).

The absence of professional integrated management information tools is illustrated – albeit anecdotally – by the expression "Kaczyński's notebooks", which circulated in journalistic commentary (Rokita). This referred to the practice of the Prime Minister – during his 2006-2007 term of office – manually recording the status of matters and commitments undertaken by members of the government. Regardless of the anecdotal nature of this example, it illustrates well that the need for current information on the state of implementation of government priorities existed earlier, but was not supported by a permanent organisational system, uniform reporting standards, or a tool enabling the aggregation of data from different ministries.

Precise research would be required to estimate the costs arising from the absence of professional project management mechanisms in public administration. Expert commentary has included estimates that increasing project efficiency could yield savings of several billion zloty annually for Poland[9].

The diagnosis and objectives set out in the SRD were thus accompanied by concepts for specific means of implementation. An integral part of the strategy was a list of so-called strategic projects. Its creation entailed the need to establish a team and tools enabling the ongoing monitoring of project implementation. Initially, these tasks were carried out within the then Ministry of Development by two departments: the Department of Development Strategy (*Departament Strategii Rozwoju*, DSR), coordinating work on the strategy, and the newly established Department of Project Management (*Departament Zarządzania Projektami*, DZP). Following the change of Prime Minister in December 2017, and in connection with the need to monitor projects implemented across all ministries, the DZP team was transferred to the Chancellery of the Prime Minister. Within the KPRM, the Government Project Monitoring Office (*Rządowe Biuro Monitorowania Projektów*, RBMP) was established on its basis. The activities conducted by the RBMP subsequently took the form of the Strategic Project Monitoring System (SMPS).

The SMPS framework, developed by the entire RBMP team, was presented in publications by Tomasz Janka, Director of the RBMP from 2017 to 2019; it is also explained on the government website dedicated to project management, which remains accessible, and in popularising publications[10]. The present article presents the logic of the system through a summary table and a diagram of institutional responsibility, discussed below.

[9] In 2022, Professor Bogdan Lent estimated that Poland could save as much as PLN 3.5 billion annually by increasing project efficiency (Polska Wielki Projekt).

[10] The doctoral dissertation defence of Tomasz Janka took place on 18 March 2026. Retrieved from: https://www.bip.pw.edu.pl/Postepowania-w-sprawie-nadania-stopnia-naukowego/Doktoraty/Wszczete-po-30-kwietnia-2019-r/Rada-Naukowa-Dyscypliny-Nauki-o-Zarzadzaniu-i-Jakosci/mgr-inz.-Tomasz-Janka, 22.05.2026. Cf. also: https://www.gov.pl/web/zarzadzanie-projektami, 22.05.2026.

Responsibility for portfolio management rested with the newly established Strategic Projects Portfolio Monitoring Council (Rada Monitorowania Portfela Projektów Strategicznych), composed of constitutional ministers (Order No. 58 of the Prime Minister, 2018). The Portfolio area concerned the definition of project scopes, their inclusion in and exclusion from the portfolio, and ongoing monitoring and reporting. Data collection was carried out through a dedicated, incrementally developed IT system – "MonALiZa" – within the System area, which also covered the development of specifications and consultation and cooperation with contractors. Organisation was the component of the SMPS encompassing the network of project monitoring offices – counterparts of the DZP – within individual ministries. Within the Guidelines area, project monitoring processes were developed, along with recommendations concerning the management of projects, programmes, and portfolios. In parallel, dedicated training courses were launched at the National School of Public Administration, and regular training and networking meetings for project implementers were organised within the People area. Table 1 summarises these six areas and the dependencies between them.

Table 1.
Components of the Strategic Project Monitoring System and their mutual dependencies

Component	Function	Interdependencies with other components
Strategic Projects Portfolio Monitoring Council	Decisions on opening/closing projects, prioritisation	Decides on the basis of data from the Portfolio and MonALiZa; authority constrained by the non-binding status of the Guidelines and by the fact that the most consequential decisions on government priorities were taken in other forums
Portfolio	Defining project scope, inclusion in/exclusion from the portfolio	Dependent on Council decisions; formally constrained by its link to the strategic document (SRD); fed with data from MonALiZa
System	Data collection and aggregation	Data entered by the BMPs; data quality dependent on the Guidelines and competences developed under the People area; partly duplicates strategic reporting (DSR)
Organisation (network of BMPs)	Implementing project management within ministries	Operates according to Guidelines lacking binding status; uneven maturity across offices
Guidelines	Standards, terminology, monitoring process	Not formally adopted by the Council; limited influence on Organisation; agile-based guidelines for selected project types remained to be developed
People	Training, community of practitioners	Strengthens data quality in MonALiZa and the implementation of the Guidelines, but no formal mechanism links these effects to the evaluation of BMPs

The diagram below (Figure 1) presents the principal bodies of the system together with their responsibilities.

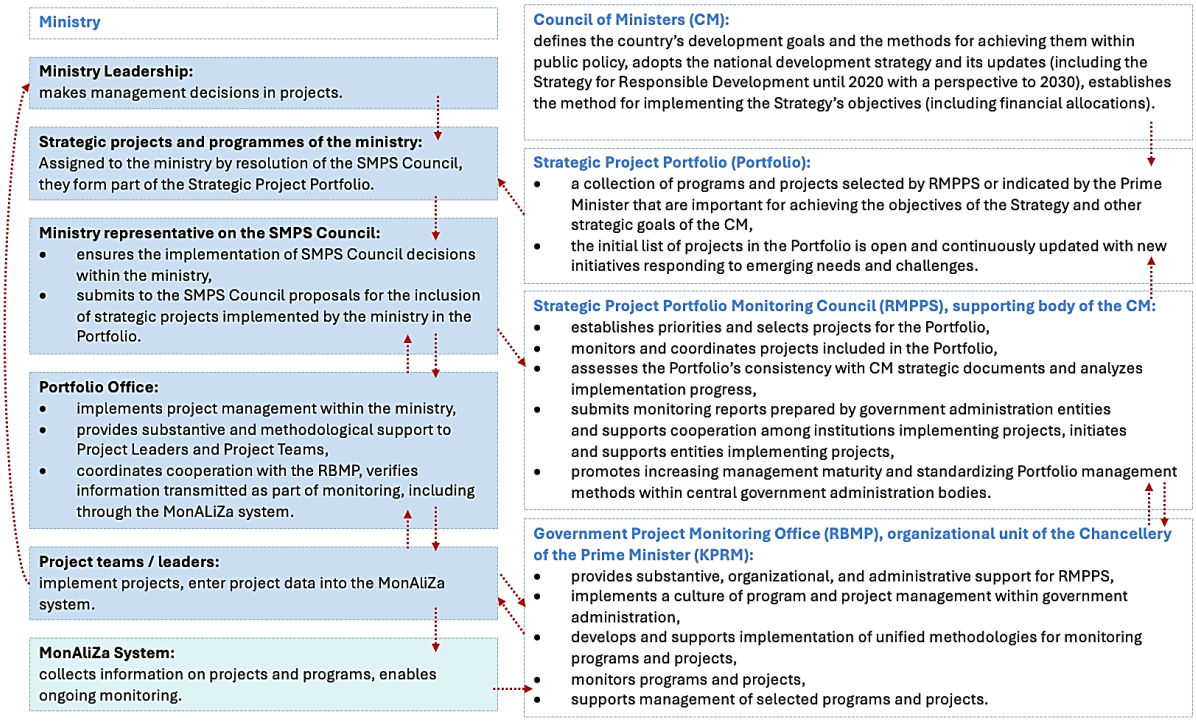

Figure 1. Structure of the Strategic Project Monitoring System.

Source: own elaboration based on Informacja o wynikach kontroli SMPS, 2022.

Figure 1 confirms that the SMPS rested not on a single tool but on an interlocking chain of institutional responsibility, from the Council of Ministers down to individual project teams.

The report produced by the RBMP research study conducted in 2023 noted "a high level of System advancement (average score of 20 points on a 24-point scale), alongside considerable variation across individual ministries (standard deviation of 3.9 points)" (KPRM, 2023). Among the achievements identified, the report highlighted – alongside the functioning of the SMPS Council – the existence of the inter-ministerial structure of the system: a Project Monitoring Office (*Biuro Monitorowania Projektów*, BMP) operated within each ministry and within the KPRM. These offices oversaw projects and programmes managed by more than 30 Programme Managers (*Kierownicy Programów*, KP) and 140 Project Leaders (*Liderzy Projektów*, LP). The report also noted the widespread application of governing principles, including a project management standard and a uniform terminology for strategic projects (KPRM, 2023). Among survey respondents, 74% confirmed the existence of project management principles within their organisations, and more than 72% declared that they applied them in the implementation of their projects (KPRM, 2023). The areas requiring further development concerned primarily: the legal grounding of project management in government administration, the strengthening of inter-ministerial cooperation, the improvement of decision-making processes, the clarification of principles for the prioritisation and selection of strategic projects, the equalisation of project structure maturity levels across offices, the strengthening of the roles of the RBMP and the BMPs, the enhancement of the competences and responsibilities of project leaders, and the further development of the project community, training provision, and the IT system (KPRM, 2023).

The Polish SMPS was not an isolated phenomenon. Comparable reflection on the projectification of public administration was taking place elsewhere in Europe during the same period. In 2017, the German Federal Office of Administration and the German Project Management Association launched the programme "Shaping Germany's Future through Projects" (Aktionsprogramm). At events resembling the Polish "Breakfasts with MonALiZa", German (Aktionsprogramm 2017) administration representatives cited public projects running as much as 73% over budget, with the nine-year delay and 250% cost overrun of Berlin Airport offered as a cautionary case (Wagner et al., 2022). Similar activity and research took place in the Nordic countries and in Ukraine (Wald et al., 2025; Jørgensen et al., 2023; Makarenko et al.).

Following the parliamentary elections of autumn 2023, the Strategic Projects Portfolio Monitoring Council was dissolved by order of the Prime Minister (Order No. 15 of the Prime Minister, 2024). The activities of the RBMP came to an end with the dissolution of the Government Analysis Centre, of which the Office was by then a part (Act of 15 May 2024). That the system could be dismantled through two administrative orders, without legislative involvement, illustrates institutionally what the Supreme Audit Office had identified as its central weakness: the absence of a statutory foundation left the entire mechanism dependent on political continuity rather than law. From the perspective of this article, this means that the SMPS constitutes a concluded – though relatively recent – case of an attempt to institutionalise the project-based approach in government administration. The conclusion of this phase should serve as an impetus for institutional learning: the systematisation of experience from the years 2015-2023, the identification of key dilemmas, and the application of the lessons drawn from them to the design of subsequent mechanisms for implementing state strategy.

4. Key Dilemmas of Institutionalising the Project-Based Approach

Portfolio, programmes, and projects constitute some of the fundamental tools for operationalising strategic plans. Information published by the MFiPR indicates that the new medium-term national development strategy is likewise to include an action plan together with projects. Tomasz Janka, drawing on Ika and Hodgson in his discussion of experience with implementing the project-based approach in the public sector, identified several typical pitfalls of this process (Ika, Hodgson, 2014, cited in Janka, 2024). Risks may arise when business solutions are implemented without accounting for the specific characteristics of the public sector, when quick results are expected, when managerial competences are insufficient (which would correspond to the provisions of the National Development Strategy to 2020), and when the specificities of local culture are not taken into account.

The pitfalls identified are extremely important, but they concern primarily the manner in which the project-based approach is implemented. The experience of the SMPS demonstrates, however, that equally significant are deeper institutional dilemmas concerning the manner of defining projects and programmes, the relationship between strategy and the day-to-day governance of the state, the legal grounding of the portfolio, the positioning of the monitoring body, and the integration of the project-based approach with existing administrative processes. Failure to resolve these dilemmas – or at least a lack of awareness of their existence – may lead to a reduction in the effectiveness of the system: limited utility of monitoring data, a decline in the quality of management decisions, and the formalisation of activities at the expense of their real impact on project implementation. The effectiveness of the project-based approach depends not only on its formal institutional construction, but also on the manner in which fundamental categories are defined, the quality of data, the relationships between actors, the allocation of responsibility, and the capacity of the administration to learn from experience. The subject outlined is extraordinarily multifaceted and requires in-depth study; the subsequent analysis therefore focuses on the following dilemmas:

- the role of strategic documents in the process of day-to-day state governance,
- the definition of a project, including the question of whether projects refer exclusively to activities implemented outside the ministry – that is, delivered to external beneficiaries – or also to undertakings conducted internally within ministries,
- the definition of a programme and its relationship to strategy, projects, and programme documents,
- the significance of implementing the project-based approach in government administration.

Other issues identified above – such as the legal grounding of the portfolio or the positioning of the monitoring body – appear in the article to the extent necessary for the discussion of these four dilemmas. Outside the scope of the present text, however, remains the necessary analysis of the linkages between the project-based approach and the budgetary process, the legislative process, management control, the risk management system, and personnel policy. This applies equally to classical principal-agent problems arising from the divergence between institutional objectives and the individual motivations of organisational participants (Szczepańska, 2017, p. 166).

4.1. What are strategies and who is responsible for their coordination?

There is no universally accepted definition of strategy in the literature. Existing definitions may be grouped into those that, first, equate strategy with a set of objectives, methods, and means; second, emphasise the importance of strategic differentiation; and third, relate to the overall functioning of an organisation (Szumowski, 2023, p. 146). In public administration too, the concept of strategy is not entirely unambiguous. In Poland, as Andrzej Zybała noted in

2012, "the concept of strategy in public administration has never acquired a settled meaning or a consistently applied definition" (Zybała, 2012, pp. 251-252). The experience associated with the SRD appears to confirm this thesis. The document introduced new elements into the understanding of governmental strategy and, through its emphasis on implementation, altered the prevailing logic of action. The ambiguity of the concept of strategy became all the more apparent when the document was expected not only to define the objectives and directions of state intervention, but also to serve as the basis for the ongoing monitoring and accountability of specific initiatives.

Historically, strategic management in Poland underwent significant change following the country's accession to the European Union.[11] The prospect of implementing structural funds provided a direct impetus for the creation of national strategies in accordance with the logic of "planning, programming, budgeting, identification, implementation, control and monitoring, and evaluation" (Szczepańska, 2017, p. 166). In 2006, the Ministry of Regional Development "counted 406 documents of a strategic character produced after 1989" (Zybała 2012, p. 251). The first key milestone in bringing order to the strategic management system was the Act of 6 December 2006 on the principles of development policy. The next government prepared a detailed document entitled *Assumptions of the Development Management System of Poland*, adopted by the Council of Ministers on 27 April 2009. It diagnosed the weakness of strategic programming mechanisms in Poland and proposed a framework comprising three categories of documents: a long-term national development strategy (a horizon of at least 15 years), a medium-term strategy (4-10 years), and nine so-called horizontal development strategies. The reform process was accompanied by, among other things, a handbook entitled *Strategic Management of Development* by Jarosław Górniak and Stanisław Mazur, published by the Ministry of Regional Development in 2012 (Górniak et al., 2012, p. 9).

Article 2 of the Act of 6 December 2006 defined development policy as "a set of interrelated actions undertaken and implemented with a view to ensuring the sustainable and balanced development of the country, socio-economic, regional and spatial cohesion, the enhancement of the competitiveness of the economy, and the creation of new jobs at the national, regional or local level". In accordance with Article 3a, it is "the minister competent for regional development who coordinates the preparation and implementation of development strategies co-financed from the state budget or from development funds originating from the European Union or other foreign sources".

Anchoring strategic responsibility within the ministry responsible for regional development strengthens the substantive character of the strategy and distances it from the day-to-day dynamics of politics. At the same time, this division remains blurred. As the authors of the MRR handbook write, "the administrative and political functions complement one another,

[11] Outside the scope of this article is the question of the role of strategy as an instrument through which European institutions may seek to limit "the room for manoeuvre and arbitrariness of political leaders representing member states." Cf. Cichocki et al., 2022, p. 18.

forming an integral whole" (Płoskonka et al., 2012, p. 62), operating within a single planning and implementation system aimed at improving living conditions in Poland. In practice, this means that action plans are developed on the basis of agreed strategic assumptions, but those strategic assumptions are themselves shaped by political choices. Successive governments bring their own diagnosis of the country's situation, their own hierarchy of objectives, and their own vision of the desired outcomes. The arrival of a new government with its own political programme therefore typically leads to a revision of strategic documents, so that they may serve as an instrument for implementing that programme. As the authors of *Strategic Management of Development* explain, development policy and specific public policies typically follow a cycle that begins with a political decision setting preliminary objectives, which are then elaborated through public deliberation before being translated into concrete strategies. Two things are established within this cycle: what a given public policy is meant to achieve, and how, by whom, and through what means those objectives are to be pursued (Płoskonka et al., 2012, pp. 73-74).

The tension between the formal status of the SRD and the expectations attached to its functions was already apparent to the authors of the ex ante evaluation. In their report, they noted that a significant factor influencing the process of drafting the Strategy – and in particular the prospects for its implementation – was the absence of a clear definition of the role, and especially the political role, that the SRD was to play. Formally, the Strategy constituted an update of the Medium-Term National Development Strategy; however, expectations emerged in the public debate that it should be treated as a direct plan for economic policy, or even as a governing programme (Raport ex ante SOR, 2016)[12]. This ambiguity had consequences not only for the way in which the SRD was communicated, but also for the design of its implementation mechanisms. If the Strategy was to be treated primarily as a document within the development policy system, the natural focus became the monitoring of objectives, indicators, and directions of intervention. If, however, it was also to serve as a government action plan, it was necessary to track progress on specific projects, decisions, and commitments undertaken by individual ministries. In practice, this led to the coexistence of two monitoring logics: the strategic and the operational – that is, the project-based.

These tensions manifested themselves above all in the manner in which the strategic project portfolio was treated. It was the portfolio that was to constitute the practical mechanism for implementing the objectives and initiatives defined in the SRD. The experience of working on the SRD clearly demonstrates the need for deeper reflection on the portfolio's place within the administration – a topic that has also been relatively rarely addressed in the academic literature (Roberts et al., 2023). In management studies, a portfolio is understood as a collection of projects, programmes, and other activities grouped on the basis of their significance for the

[12] Andrzej Zybała distinguishes between documents produced on the basis of the Act on the principles of development policy and so-called strategic governing plans; cf. Zybała, 2012, pp. 272-273.

achievement of an organisation's strategic objectives[13]. The portfolio perspective enables the prioritisation of initiatives, the coordination of resources, the monitoring of progress, and decision-making regarding the launching, continuation, modification, or closure of undertakings. Understood in this way, the portfolio is thus an instrument for managing the relationship between strategy and its implementation[14].

The difficulties associated with defining the relationship between the strategy and projects were already apparent at the ex ante evaluation stage of the SRD. The flagship projects were described in a manner the evaluator found "very general and laconic", which made it impossible to properly assess their likely effects (Raport ex ante SOR, 2016). Similarly, in the case of the so-called project fiches, the evaluator recommended a further assessment of whether their provisions remained consistent with the final version of the Strategy for Responsible Development (Raport ex ante SOR, 2016). At the present stage it is difficult to reconstruct the process of assessing the consistency of projects with the strategy, which should have been carried out between the preparation of the evaluation report and the adoption of the SRD[15].

Despite the absence of this formal evaluation, the decision was taken to treat the list of projects as an annex to the strategy. This solution produced ambivalent consequences. On the one hand, it may have strengthened the pressure for the actual implementation of the initiatives proposed by the ministries. On the other hand, the adoption of the strategy together with the list of projects by resolution of the Council of Ministers meant that an instrument inherently dynamic in character lost part of its flexibility. Any change to the portfolio would require a process equivalent to updating a strategic document and a new resolution of the Council of Ministers.

The subsequent history of the portfolio illustrates well the unresolved dilemmas of strategic management in Polish government administration. The Act on the principles of development policy merely states that "the main public bodies participating within the government in the process of coordinating national development policy are: the Prime Minister and his advisory body, the Coordination Committee for Development Policy, the Minister for Regional Development, and other ministers, in particular the Minister of Finance" (Płoskonka et al., 2012, p. 76). Several tensions arising from this arrangement deserve attention.

First, from the perspective of monitoring strategic projects, the placement of the body responsible for the country's principal strategic document within one of the ministries means that two decision-making centres coexist within the government: the ministry responsible for regional development and the Chancellery of the Prime Minister. The KPRM is, after all,

[13] Cf. *The Standard for Portfolio Management*. Project Management Institute; *Management of Portfolios*. AXELOS; ISO 21504:2015.

[14] Handbooks published by the KPRM adopted a similar approach, defining a portfolio as "a collection of programmes and projects and other work selected according to specified criteria and grouped for the purpose of effective and efficient management and control." Cf. Ogonowski, Podkowińska, 2020.

[15] The selection of projects always has a political dimension. The ex ante evaluation also called for verification of the consistency between project fiches and the final SRD (Raport ex ante SOR, 2016).

the body that provides administrative support to the Prime Minister and the Council of Ministers. Under Article 146 of the Constitution, it is the Council of Ministers that conducts the internal and foreign policy of the Republic of Poland, and under Article 146(4)(4) it coordinates and supervises the work of the organs of government administration (Constitution of the Republic of Poland, 1997, Art. 146). This tension was reflected both in the history of the monitoring team – which was transferred from the Ministry of Development (later the Ministry of Investment and Development) to the KPRM – and in the composition of the Strategic Projects Portfolio Monitoring Council. Its first chair was the Chair of the Coordination Committee for Development Policy. In this way, an attempt was made to preserve the unity of responsibility for coordinating the implementation of the strategy, while simultaneously locating the monitoring function within the KPRM, where the Prime Minister was, at least in theory, the natural recipient of information on project status.

Second, the equivalent of the portfolio updating process was to be the decisions taken by the Strategic Projects Portfolio Monitoring Council, which – on the basis of project charters and closure reports submitted by the ministries – decided respectively on the opening and closing of project initiatives. This mechanism partially restored to the portfolio the flexibility that had been constrained by its association with the strategic document. At the same time, it had significant limitations: the most important decisions concerning government priorities were naturally taken in other forums, primarily the Council of Ministers and government committees. The SMPS Council may therefore be regarded as having served a compensatory function: it organised information and formalised decisions concerning the status of projects, but did not resolve the problem of dispersed decision-making authority. During the course of the RBMP's activities, the idea emerged of potentially linking monitoring to the work of the Standing Committee of the Council of Ministers, but the COVID-19 pandemic interrupted reflection on this matter.

Third, the tension between the strategic and operational logics was reflected in the coexistence of strategic and project-based monitoring[16]. This division was grounded in the document *System of Development Management of Poland* (System zarządzania rozwojem Polski, 2018). However, the formal distinction of roles did not guarantee transparency or eliminate the duplication of activities. Strategic monitoring also encompassed data on ongoing initiatives, and the situation was further complicated by the assignment of some of these initiatives to individual sectoral strategies. After 2018, work was undertaken on extracting quarterly strategic reports collected by the DSR from the MonALiZa system; however, in practice a significant proportion of the reporting obligations of the ministries overlapped.

[16] For the monitoring of key strategic indicators, the system at https://strateg.stat.gov.pl/#/ is of significant importance.

The strategy-and-portfolio dilemma thus consisted in the tension between the need to anchor projects firmly within the state's strategic objectives and the necessity of preserving the flexibility appropriate to a management instrument. The experience of the SMPS demonstrates that the effective implementation of a strategy requires not only the adoption of a document and the identification of projects, but also a clear determination of who manages the portfolio, by what procedure it may be updated, what decisions are to follow from monitoring, and how responsibility is divided between the centre of government and the ministry responsible for development policy.

4.2. What are projects and who implements them?

The implementation of the project-based approach began as early as the stage of drafting the SRD. According to the ex ante evaluation report, a novelty in its preparation – compared with the Medium-Term National Development Strategy – was the solicitation of proposals for specific projects from the ministries (Raport ex ante SOR, 2016). Although, as the authors of the report maintain, the preparation of the SRD and the previous strategy followed a similar course, the exception was precisely "the proposed implementation system, which in the case of the SRD was accompanied by the preparation of project fiches, as well as the development of procedures related to project management and the preparation of a list of entities together with the detailed scope of responsibility of each of them in respect of the coordination and monitoring of the SRD" (Raport ex ante SOR, 2016). Drawing on good practices described in the PMBOK Guide, the fiches were to contain the data necessary for the launching of projects (Raport ex ante SOR, 2016).

The available materials do not make it possible to determine unambiguously whether the call for projects was accompanied by a definition of a project. The Strategy itself contained a broadly general distinction between types of initiatives rather than a definition of a project in the managerial sense: "Strategic projects constitute a bundle of undertakings of a varied character, or are targeted [punktowe] and are intended to stimulate other activities. Flagship projects, by contrast, are directed at the creation of specific products (tangible or intangible) or services with a view to enabling their emergence on the market and achieving a positive impact on the state of the Polish economy" (Strategia na rzecz Odpowiedzialnego Rozwoju, 2017, p. 16).

According to the definition given in the encyclopaedia of management, a project is a temporary, unique undertaking with a defined objective, a beginning and an end, aimed at producing a specific product, service, or result (Encyklopedia Zarządzania "Projekt" 2026). The responses to the call for projects issued by the then Ministry of Development to the ministries revealed considerable heterogeneity in the understanding of the concept of a project

within central administration[17]. It appears that by the time the Strategy was adopted, this heterogeneity had been reduced only partially. Even a cursory reading of the annex to the SRD and a comparison of the project table with the descriptions contained in the text of the Strategy demonstrate that a very diverse range of initiatives was brought together under the common label of "project." Alongside undertakings meeting the classical criteria of a project – such as "Common Ticket" – and large infrastructure ventures, such as "Intermodal Freight Terminal", the annex also included government documents, public programmes, and packages of sectoral measures. For example, the "Framework Plan of Action for Organic Food and Farming 2014-2020" was a programme document in character, while "Independent 2018" was a programme[18]. The project entitled "Academy for Innovation Managers" was described as "a programme addressed to enterprise managers", (Strategia na rzecz Odpowiedzialnego Rozwoju, 2017, p. 92) and "Efficient Healthcare" as "a package of programmes for the improvement of the situation in healthcare" (Strategia na rzecz Odpowiedzialnego Rozwoju, 2017, p. 284).

This problem was not purely terminological in nature. The manner in which a project was defined determined which initiatives could be included in the portfolio, what information needed to be collected about them, who should be responsible for their implementation, and according to what criteria progress and completion could be assessed. The absence of an unambiguous definition thus impeded not only the ordering of the project list, but also the construction of a coherent management information system, since it necessitated time-consuming work to establish, on a case-by-case basis, the scope of initiatives, their expected results, the allocation of responsibility, and the manner of their reporting. Moreover, not all civil servants were prepared to formulate concise management information.

The division of initiatives in the table into regulatory categories (e.g. "Concept for Changes to the Institutional and Regulatory Environment of Industry" and "Landscape Audits"), programme categories (e.g. "State Procurement Policy" and "Raw Materials for Industry"), and comprehensive categories (e.g. "Plant Breeding Support Programme in Poland" and "EXPO Exhibitions") may be interpreted as an attempt to address this challenge. These categories were, however, explained only superficially (Strategia na rzecz Odpowiedzialnego Rozwoju, 2017, p. 386). Intuitively, one might assume that regulatory projects concerned primarily changes to the law, programme projects the creation of policies or programmes, and comprehensive projects the implementation of complex packages of measures. Such a distinction did not, however, resolve the ambiguities. Particularly unclear was the meaning of the category "programme project," and an analysis of the names and descriptions of the projects points to considerable arbitrariness in the assignment of initiatives to particular types. For example,

[17] The models presented by Płoskonka et al. (2012, p. 88) focused on policy monitoring and did not treat projects as a distinct management unit, which may have contributed to later difficulties in implementing the project-based approach.

[18] In the SRD, the initiative is described as a programme aimed at building social capital and civic engagement around the centenary of Poland's independence (Strategia na rzecz Odpowiedzialnego Rozwoju, 2017, p. 288).

"Concept for Changes to the Institutional and Regulatory Environment of Industry" encompassed not only a regulatory component but also the preparation of an industrial support system (Strategia na rzecz Odpowiedzialnego Rozwoju, 2017, p. 82). Reducing a reform to legislative changes seems a considerable oversimplification. Similarly, "Landscape Audits" combined a legislative component with the actual identification and assessment of landscape resources (Strategia na rzecz Odpowiedzialnego Rozwoju, 2017, p. 349). It is also difficult to explain unambiguously why "State Procurement Policy" was classified as a programme project, while "Plant Breeding Support Programme in Poland" was classified as a comprehensive project.

The case of the SRD illustrates well the problem of projectification described in the literature, in which "project" becomes a word-in-use, employed to describe very different initiatives and for very different purposes (Jałocha, 2025). This ambiguity is reinforced by the polysemy of the term "project" in legal and administrative language. In legislation, "project" denotes both a draft legal act initiating the law-making procedure and technical documentation, an architectural or urban design, and – in the area of development policy and public finance – an undertaking implemented within a programme, often associated with a decision, contract, or funding from public sources, including European funds. As a result, the same word may refer to a proposed legal norm, documentation, an investment activity, a project funded from EU resources, or an element of a development programme.

Of particular significance is the Act on the principles of development policy, in which projects appear as an element of the implementation of programmes (operational and development). Such initiatives are treated "as the lowest element of the implementation framework of a given strategy. They are implemented on the basis of a decision or a concluded agreement" (Płoskonka et al., 2012, p. 76). The Public Finance Act of 27 August 2009 uses the concept of a project primarily in reference to undertakings financed from the state budget, such as research and development, educational, or infrastructure projects. The Act of 28 April 2022 on the principles of implementing tasks financed from European funds in the 2021-2027 financial perspective (Article 2(22)) defines a project as an undertaking aimed at achieving an assumed objective defined by indicators, with a specified beginning and end of implementation, submitted for or covered by EU funding from one of the structural funds, the Cohesion Fund, or the Just Transition Fund within a programme.

In this way, definitional ambiguity was combined with a second problem: the question of who, within public administration, is the appropriate implementer of a project. Public administration operates within a multi-level framework of institutions, subsystems, and dependencies with its environment. The results of its activity may therefore be considered at least at two levels: as results produced within administrative units, and as effects achieved in society or the economy through the aggregate of many activities, undertakings, and public interventions (cf. Płoskonka et al., 2012, p. 62). From the perspective of monitoring strategic projects, this distinction is of fundamental importance.

In one established understanding of public projects, the administration is not a direct implementer but rather an organiser, funder, commissioner, or regulator of activities carried out by other entities. In the understanding proper to development policy, public finance, and European funds, a project is often an undertaking implemented by a beneficiary or contractor, rather than directly by a ministry. Projects are then carried out through competitions, contracts, public procurement, public-private partnerships, or other forms of service contracting (Wiatrak, 2017, p. 238). This understanding is consistent with the logic of New Public Management, in which the administration sets objectives, provides resources, establishes rules, and accounts for outputs, but does not necessarily carry out all activities itself (Bratkowski, 2009, p. 131). In this sense, the implementers of projects are frequently entities applying for EU funds or other resources allocated by managing authorities or government agencies (Kędzierski, 2022).

A particular instance of this understanding of a project is that of projects financed from European funds. In their case, the literature draws attention to the risk of a shift in emphasis from the achievement of public outcomes to the formal expenditure and accounting of funds. Jerzy Bratkowski described the implementation of EU projects as a multi-level collective action problem, in which the primary task becomes the "processing" of the allocated resources (Bratkowski, 2009, pp. 151-152). In its most extreme form, this leads to a situation in which the closure and accounting of a project begins to be treated as a success regardless of the broader effect of the intervention.

At this point a fundamental dilemma emerges: what is the project-based approach in government administration actually supposed to concern? Is it about project management – understood as a set of techniques, tools, and methodologies serving the efficient conduct of a specific undertaking – or about managing by projects – understood as a broader organisational and strategic philosophy (Turner, 1993)? In the first conception, a project is primarily a unit for the implementation and accountability of activities. In the second, it becomes a way of organising the work of the state around priorities, results, responsibility, and learning. The answer to this question has practical consequences. If "project" denotes an external initiative financed or contracted by the administration, the system monitors primarily the implementation of policies through financial, regulatory, and organisational instruments. If "project" denotes an internal undertaking of a ministry, the system monitors the capacity of the administration to organise its own work. If "project" denotes an element of a strategy, the portfolio becomes an instrument of strategic state governance. If, however, "project" denotes any "topic to be delivered", the system risks conceptual inflation, an increase in reporting burdens, and a weakening of the decision-making function of monitoring. For this reason, the stronger legal grounding of the project-based approach postulated by the Supreme Audit Office should be preceded by an answer to the question of what is to be monitored, which meaning of the project-based approach is to be the subject of regulation and to what extent. Nevertheless, even if a single implementation methodology cannot be applied

uniformly across such diverse initiatives, all of them require continuous improvement in the quality of their management – particularly in terms of the clarity of responsibility, the reliability of management information, and the coherence of decision-making processes.

4.3. What are programmes?

The Strategy for Responsible Development indicated that the document constitutes "a point of reference for the construction of all policies, programmes, and implementation projects", while at the same time making repeated reference to "government programmes" (Strategia na rzecz Odpowiedzialnego Rozwoju, 2017, pp. 8, 68). This was not, however, accompanied by any consistent explanation of how a programme differs from a project, a public policy, a programme document, or a package of interventions. As a result, within the SRD the concept of a programme functioned simultaneously in several meanings: as an implementation document, a name for a public intervention, a collection of interrelated projects, and an element of political communication.

A visible manifestation of this inconsistency was the manner in which the so-called flagship projects (sic!) were presented (Strategia na rzecz Odpowiedzialnego Rozwoju, 2017, pp. 77-78). In their descriptions, the terms "project" and "programme" are used interchangeably. For example, "Modern Products of the Shipbuilding Industry" was presented as a programme encompassing the project "Batory", while "Programme Electromobility" was presented as a whole encompassing the projects "E-bus" and "Electric Car". At the same time, other initiatives of a similar character were classified differently: "Eco-Construction" was described as a programme, "Polish Furniture" as a project, and "Intelligent Mine" as a programme in the flagship project table.

The ambiguity was further deepened by the relationship between the description of flagship projects and the strategic project table. Although the names of flagship projects were in principle not repeated in the table, some entries concerned similar or related areas of intervention, without any clear explanation of their mutual relationship. For example, the strategic project table contained the "Electromobility Development Programme", which was to constitute a form of implementing the "Electromobility Development Plan" adopted by the Ministry of Energy, while in the flagship projects section the "Programme Electromobility" appeared separately, encompassing the projects "E-bus" and "Electric Car". Similarly, the initiative "Polish Medical Devices" appeared in the descriptive section as support for research, development, and commercialisation of medical devices, while in the strategic project table a similar subject reappeared as "Pharmaceutical and Medical Devices Policy" (Strategia na rzecz Odpowiedzialnego Rozwoju, 2017, pp. 77-78). At this point the vocabulary of the strategy introduces the concept of "policy", which likewise does not have an unambiguous meaning.

Additional confusion in the vocabulary of public management is caused by initiatives in which the word "programme" functions as a proper name or a colloquial designation for a government intervention. One example is "Programme 500 Plus," implemented on the basis of the Act of 11 February 2016 on state assistance in child-rearing (Act of 11 February 2016). In this case, the designation "programme" refers primarily to a recognisable public intervention and an instrument of family policy, and does not denote a development programme within the meaning of the Act on the principles of development policy, nor a programme as a management structure encompassing a bundle of interrelated projects. A similar function is performed by, for example, the "Good Start" programme, which is support paid at the beginning of the school year, and many other social benefits ("Good Start" programme, 2018).

The practical consequences of this ambiguity were apparent in the creation of the strategic project portfolio. "Programme 500 Plus" was initially submitted to the portfolio by the Ministry of Family, Labour and Social Policy as a project. It was subsequently closed, since it was difficult to demonstrate that regularly paid benefits were intended to lead to the creation of a unique product, service, or result. A decision was therefore taken within the MonALiZa system to monitor benefits instead. It is worth noting that at that stage no pathway had been developed for transferring monitoring to the STRATEG system, which could itself be a subject for further reflection.

This example demonstrates that the ambiguity of concepts was not purely a terminological problem. It translated into the day-to-day practice of portfolio management: establishing the relationships between initiatives, defining project outputs, distinguishing ongoing activities from time-limited undertakings, and deciding what should be subject to project monitoring and what to other forms of monitoring. This kind of clarificatory work continued throughout the entire period of the Government Project Monitoring Office's activity.

At the legal level, the key point of reference for the understanding of programmes in Polish public administration is the Act of 6 December 2006 on the principles of development policy (Act of 6 December 2006). In accordance with Article 4(1), development policy is conducted on the basis of development strategies, programmes, programme documents, and public policies. Article 15(1) defines programmes as "documents of an operational and implementation character established for the purpose of implementing development strategies, specifying the actions provided for implementation in accordance with the programme implementation system and the financial plan, which constitute an element of the programme". A programme in this sense is therefore primarily a document adopted through a specified procedure, rather than a management structure encompassing interrelated projects, outputs, benefits, roles, and decision-making mechanisms.

From the perspective of good practices in project and programme management, this approach is insufficient, since it does not encompass the organisational dimension of a programme: the manner of managing interrelated undertakings, the coordination of dependencies, the monitoring of benefits, and decision-making in the course of implementation

(Encyklopedia Zarządzania, "Program", 2026). For this reason, the recommendations developed by the KPRM emphasised that "the adoption of a document constitutes only a small fraction of the activities forming part of a programme understood from a managerial perspective. In each case it is necessary to appropriately plan, organise, coordinate, and control both the activities preceding the adoption of the document and the projects implemented on its basis" (Strojny, Szymborska, 2021). The legal association of the concept of "programme" with a specific type of document should not eliminate from the discussion of public administration reflection on the proper management of interrelated projects.

It should also be borne in mind that in administrative practice a programme understood as a document may also serve as the basis for the identification of a project portfolio. A good example is provided by successive national road construction programmes, which specify lists of planned road investments. This does not, however, automatically mean that such a programme is managed as a programme in the methodological sense – that is, as a structure serving the coordination of interrelated projects and the achievement of common benefits. A further example of ambiguity is provided by the so-called First Speed Programmes described in the SRD, associated with the National Smart Specialisations (Strategia na rzecz Odpowiedzialnego Rozwoju, 2017, pp. 10, 69, 88). The Strategy defined the criteria for their identification and indicated an open catalogue of areas, including medical engineering technologies, innovative agri-food technologies, and environmentally friendly transport solutions, among others (Strategia na rzecz Odpowiedzialnego Rozwoju, 2017, p. 89). It did not, however, explain precisely the relationship between these programmes and the strategic projects.

The dilemma concerning programmes thus consisted in the fact that the same concept encompassed within public administration several different orders: legal, strategic, managerial, and communicative. A programme could denote an operational and implementation document, the name of a public intervention, a package of sectoral measures, a collection of projects, or an instrument for achieving benefits. Without distinguishing between these meanings, it was difficult to determine unambiguously what should be the subject of project monitoring, who is responsible for programme implementation, what outputs and benefits are to be achieved, and when a programme may be considered complete. A further question worth exploring is whether the programme instrument was sufficiently utilised for its potential to coordinate interrelated cross-ministerial initiatives — one of the functions it may be particularly well suited to perform.

4.4. What does the implementation of the project-based approach mean?

Both the Supreme Audit Office report and the report from the study conducted by the RBMP called for greater "legal grounding of project management in government administration"[19]. The SAO indicated that the methodological handbooks developed by the RBMP "were not submitted to the Council for adoption and therefore did not have a binding character. As a result, government administration units applied the project-based approach in a varied manner", (Informacja o wynikach kontroli SMPS, 2022) which the Office considered inconsistent with the provisions of the SRD and the System of Development Management of Poland, which imposed an obligation to implement the project-based approach in government administration. This postulate accurately identified one of the problems of the SMPS, but did not exhaust the question of what the implementation of the project-based approach in government administration means in practice.

The postulate of providing a legal basis for the activities conducted by the RBMP is consistent with the fundamental principle of legalism in public administration[20]. At the same time, the question of implementing the project-based approach was not reducible to the issue of the formal grounding of monitoring. It concerned more broadly the institutional conditions for implementing the project-based approach in government administration: the absence of a shared definition of project and programme, the lack of a uniform project management language, the limited maturity of tools, and the attempt to introduce a new management logic into a bureaucratic order.

In the publication on knowledge management mentioned in the introduction, Ikujiro Nonaka and Hirotaka Takeuchi describe the process of creating innovation as an activity closely associated with the externalisation of tacit knowledge into explicit knowledge (cf. Nonaka, Takeuchi, 2000, p. 112). This process begins with the search for appropriate analogies and metaphors illustrating the target product. Applying this method, bureaucracy is traditionally compared to a machine (the bureaucratic machine), which can be fine-tuned to function efficiently, like a Swiss watch (cf. Cichocki et al., 2022). The mechanism, however, has an incurable tendency to fall into the so-called vicious circle of bureaucratisation, expanding its competences and progressively stripping itself of flexibility (cf. Koźmiński et al., 2023,

[19] It should be noted, however, that at that time the system was grounded in the following documents: the Act on the Council of Ministers of 8 August 1996 (*Dz.U.* of 2022, item 1188, as amended); Resolution No. 8 of the Council of Ministers on the adoption of the Strategy for Responsible Development to 2020 (with a perspective to 2030) of 14 February 2017 (*M.P.*of 2017, item 260); Order No. 58 of the Prime Minister on the Strategic Projects Portfolio Monitoring Council of 20 April 2018 (*M.P.* of 2021, item 247, as amended); Resolution No. 1/06/2018 of the Strategic Projects Portfolio Monitoring Council on the adoption of the rules of procedure of the Strategic Projects Portfolio Monitoring Council (as amended); Resolution No. 5/2022 of the Strategic Projects Portfolio Monitoring Council on the adoption of the project monitoring process for the portfolio of the Strategic Projects Portfolio Monitoring Council; Resolution No. 7/2022 of the Strategic Projects Portfolio Monitoring Council on the implementation of the project-based approach in ministries.

[20] In accordance with Article 7 of the Constitution of the Republic of Poland, organs of public administration act within the limits of and on the basis of the law.

p. 259). Bureaucracy emerged in a different historical context and was suited to complicated – but not complex – problems (cf. Snowden, et al., 2007). Given the complexity of today's world, one interesting analogy for the needs of public management is the comparison to a "special unit" – an autonomous team that responds flexibly to emerging challenges (cf. Edmondson, 2017).

In management theory, a related concept is James Brian Quinn's notion of so-called incremental strategies (cf. Jemielniak, 2012, p. 86). It assumes that, given the limited capacity to predict the future, organisations should preserve the capacity for learning and correcting actions in the course of implementation. Development depends, after all, "on social experimentation and social innovation – that is, on institutional evolution" (Hausner, 2012, p. 37.) From this perspective, the implementation of the project-based approach in public administration should not be treated as a one-off adoption of a standard, but as the gradual development of organisational capacities. From a managerial standpoint, such an initiative may be understood more as a change programme than as a single implementation project: it encompasses people, processes, technologies, roles, decision-making mechanisms, and the manner in which management information is used (cf. Becker, 1999). This corresponds to the necessity of a holistic approach to change proposed by Tomasz Janka (cf. Janka et al., 2019).

This does not, however, amount to a simple opposition between law and flexibility. The example of the activities of the Polish Financial Supervision Authority during the COVID-19 pandemic demonstrates that some public institutions were capable of using existing legal frameworks in a more adaptive manner, treating legislative change as a last resort (cf. Kędzierski et al., 2022). As the report edited by Marcin Kędzierski indicates, in the dynamic conditions of the pandemic, excessive casuistry and the slowness of the legislative process could have undermined the effectiveness of action. It should be borne in mind, however, that such an approach carries the risk of reducing transparency and public accountability, since it is the legislative process that creates the space for debate, the justification of decisions, and public scrutiny (cf. Kędzierski et al., 2022).

The dilemma of implementing the project-based approach thus consists in the fact that public administration needs both clear foundations for action and room for the flexible organisation of work. This applies both to the overall process of implementing the project-based approach and to the implementation of each individual initiative. This gives rise to the question of whether – given that the efficient and effective operation of public administration is already an element of the normative standard of good administration – project management might not be treated as a technique for realising that standard. The principle of efficiency may justify the choice of internal organisational methods, provided they fall within the scope of the tasks and competences statutorily entrusted to the body concerned (cf. Gołębiowska, Zientarski, 2017, pp. 60-61). Those implementing the project-based approach should ask themselves whether the objective is the adoption of documents or a long-term change of culture. Legal grounding of

the indicated practices without a change in attitudes may lead to so-called performative compliance (window-dressing)[21].

In this context, the Supreme Audit Office's postulate concerning the legal sanctioning of the project-based approach should also be considered in light of the emerging trend of so-called de-projectification, understood as a retreat from project culture. As Beata Jałocha indicates, projectification may be superficial, performative, and insufficiently embedded in the management of an organisation (cf. Jałocha, 2025). Organisations may abandon some project management practices when they encounter difficulties in scaling agility, transferring project results to operational activities, or when the project-based mode of working was primarily the result of external funding or a political decision (cf. Jałocha, 2025). The limited scope of research does not, however, make it possible to determine the scale and exact character of the phenomenon. From this perspective, the implementation of the project-based approach does not mean merely the establishment of an obligation to apply a methodology – or methodologies, different ones for different types of projects. It means rather the durable creation of the administration's capacity to define projects and programmes, manage the portfolio, make decisions on the basis of management information, learn from experience, and translate project results into lasting institutional change.

The changes being implemented require the combination of multiple logics – including the legal, organisational, financial, competence-related, process-related, and technological (cf. Kędzierski et al., 2022). In this sense, the implementation of the project-based approach may be compared to the shaping of a development model. In the publication mentioned above, Mazur and Górniak, writing about development models, argue that they "are not planned but rather discovered", since they constitute the resultant of reflection, learning, the imitation of others' solutions, and the influence of many actors (Górniak, et al., 2012, p. 9). The activities of the RBMP arose from the need at that time to create an efficient system for implementing initiatives, but were conducted within a specific structural and institutional context that created particular opportunities while simultaneously imposing strong constraints (cf. Górniak et al., 2012). The success of the undertaking depended on the cooperation of many actors with divergent interests, nor were conflicts absent.

From this perspective, the change was incremental in character and resembled more a process of "pushing through" existing institutional arrangements than the implementation of a pre-designed model (Strumińska-Kutra, 2012). In such conditions, the outcome tends to be not so much elegant institutional constructions as "clumsy solutions" – partial, compromise-based, and imperfect (Strumińska-Kutra, 2012). This need not signify failure, but requires an awareness that, as Strumińska-Kutra emphasises, institutional changes produce both

[21] Examples of unimplemented legal provisions are given by, among others, Zybała, 2012, p. 355.

intended and unintended consequences[22]. Such consequences must also be taken into account in the context of the implementation of individual projects and programmes from the portfolio.

Another element of the dilemma identified above that deserves mention is the question of the implementation model. In the years 2013-2015, activities aimed at promoting management by objectives and process management were carried out with the participation of a large external consulting firm, within a project co-financed from the European Social Fund (Procesy, cele, kompetencje…, 2015). In the case of the project-based approach, the activities conducted between 2015 and 2023 were carried out primarily by a team of DZP/KPRM officials in cooperation with representatives of the ministries, with substantive support from the National School of Public Administration and professional organisations such as IPMA and PMI[23]. Both models have different consequences. A large consulting project can provide scale, resources, and the rapid production of methodological outputs. Work conducted within the administration, by contrast, favours the building of a sense of ownership, direct and regular contact with officials carrying out tasks, and the gradual creation of a community of practitioners. This does not resolve which model is better, but demonstrates that the implementation of the project-based approach is also a decision about the manner of organising institutional change.

5. Conclusion

Research concerning the years 2015-2023 in public institutions emphasises the dominant atmosphere of that period, associated with the necessity of "delivering on topics" – that is, finalising projects and achieving the assumed indicators (cf. Kędzierski et al., 2022). Earlier, however, the ex ante evaluation report of the SRD had stressed that "the possibility of effectively implementing the SRD is contingent on carrying out a reform of the entire system of state governance", while the Strategy itself addressed this issue only cursorily (Raport ex ante SOR, 2016). The experience of the SMPS may be read as an attempt to deal practically with this contradiction: between the need for the efficient implementation of government priorities and the institutional immaturity of the conditions for their monitoring, coordination, and accountability.

[22] The extent of the so-called ungovernability of the areas concerned – which in the projects formulated frequently extended beyond the scope of direct government responsibility – would also be worth investigating.

[23] Further research is needed on the role of professional associations in administrative reforms. As Wald et al. (2025) note, professional associations act as institutional agents, promoting standards, certifications, and professional norms, thereby contributing to the institutionalization of project management as both a discipline and a profession.

The analysis conducted demonstrates that the project-based approach in government administration is not merely a technique for organising work. It is an element of broader institutional design, which requires an awareness of a range of dilemmas: what a strategy is and who is responsible for its coordination; what should be regarded as a project; how a programme as a document differs from a programme as a management structure; how the strategic project portfolio should be grounded; who should be responsible for monitoring; and in what manner management information should translate into decisions. Any formalisation of the project-based approach should be preceded by a determination of whether it is primarily project management, managing by projects, or both levels that require regulation. Translating this into practice may require the following concrete steps.

First, the determination of which level requires regulation should proceed incrementally, through piloting and revision rather than a single binding decision. The implementation of the project-based approach should itself be treated as an incremental change programme, with explicit space for testing and revising solutions before they harden into a fixed model (cf. Section 4.4). Second, legal grounding is necessary, but does not substitute for conceptual and organisational resolutions. In concrete terms, this means legal anchoring with room for adaptation: a statutory basis for the continuity of the monitoring function, so that its survival does not depend on a single administrative order, while avoiding the casuistry that would lock the system into a single, uniform procedure. Third, the strategic project portfolio should be integrated into the main system of state governance rather than functioning as an isolated add-on. This requires a transparent procedure for opening, closing, and reprioritising projects, independent of the cycle of updating the strategic document itself, as well as explicit links between project monitoring and the budgetary and legislative processes, so that project status can inform – and be informed by – financial and legal decisions. Project management should be embedded within existing administrative workflows rather than creating a parallel circuit of documentation and reporting. This would also require closer reflection on the relationship between local Project Monitoring Offices in ministries and political cabinets, in order to ensure a smooth flow of management information to its intended recipients, including the Prime Minister (cf. Section 4.1). Fourth, project-based monitoring and strategic monitoring should be clearly distinguished rather than left to overlap, as occurred between the MonALiZa system and strategic reporting on the SRD's indicators. A defined process is needed for moving from operational monitoring of outputs to strategic monitoring of results and broader development indicators. In practice, this means formalising how data flows from project-level systems such as MonALiZa into indicator-based platforms such as STRATEG. Fifth, the competences, accountability, and career incentives of Programme Managers and Project Leaders require clarification, rather than being treated as an addition to existing duties. Sixth, the mandate of the network of Project Monitoring Offices should be strengthened to resolve cross-ministerial dependencies, rather than relying solely on the Council as an escalation point. Seventh, differentiated guidelines should be developed for different types of projects, setting out how

data should be collected and verified for each; the competence to apply them consistently should be built through a broad training programme. Finally, a mechanism – institutional, archival, or both – is needed for transferring accumulated experience and personnel knowledge across changes of government, so that lessons of the kind drawn in this article are not lost with the dissolution of the bodies that generated them.

None of these measures resolves the tensions underlying the project-based approach as such, since they arise from tensions inherent in the functioning of public administration: between stability and flexibility, legalism and efficiency, politicisation and professionalisation, and planning and learning in action[24]. The experience of public administration also demonstrates that, owing to the sensitive character of some information and the interpenetration of political and administrative aspects, even the most elaborate methodological and IT systems will not eliminate the need for informal, individual forms of recording management information – a kind of "notebook". All the more important, therefore, is the very recognition of these tensions and their conscious management[25]. Without such awareness, the projectification of public administration may lead to an increase in reporting burdens, the formalisation of activities, and the performative adoption of methodologies, rather than to a genuine enhancement of the state's capacity to implement appropriate, complex public interventions.

This risk is reinforced by the dominant model of accountability in Polish public administration, concentrated on procedures, the avoidance of errors, and the minimisation of risk. As Karol Olejniczak diagnoses, this stems from the twentieth-century, mechanistic conception of bureaucracy, in which public administration was expected primarily to execute repetitive and routine processes (cf. Olejniczak, 2012). A narrowly conceived implementation of the project-based approach could, in such conditions, lead to "the paralysis of actors' imagination by the process itself", "thinking in the language of regulations and programmes", and "a fragmentary perception of activities" (Bratkowski, 2009, p. 152). Changing this paradigm requires not only new tools but, according to Olejniczak, also "a redefinition of errors and failures", "a change in accountability criteria", and greater acceptance of learning from imperfect solutions (Olejniczak, 2012).

A separate subject of research could be the question of the extent to which the Strategy for Responsible Development was precisely such a "sufficient imperfection" – a document that, despite not having fully designed a project management system, created the basis for monitoring and accountability of specific initiatives. In this sense, the SMPS too may be treated as a case of "sufficient imperfection". The solution was incomplete, developed incrementally, and burdened with numerous tensions, but at the same time it made it possible to accumulate experience that had previously been lacking in government administration. In advisory practice,

[24] Owing to the sensitive character of information and the interpenetration of the political and administrative aspects, IT systems will not replace individual forms of recording management information ("notebooks").

[25] Nassim Nicholas Taleb argues that "contrary to social science theories, almost no significant discoveries and technologies are the fruit of projects and plans – they are simply Black Swans" (Taleb, 2020).

a similar phenomenon is sometimes referred to as a "buffer project" (“projekt zderzak”) – a first, often imperfect undertaking that absorbs resistance, reveals barriers, and familiarises actors with the direction of change. Research on public sector reforms also demonstrates that a first attempt may end in failure, while a second, conducted in already altered political and cognitive conditions, proves successful (Olejniczak, 2012). The failure or incompleteness of the first initiative need not therefore be a loss pure and simple; it may serve a preparatory function, creating the conditions for the later acceptance of solutions that previously met with resistance. It is also worth following the experience of other countries, particularly Germany, although the diversity of European administrative models limits the possibility of straightforward transfer of solutions (cf. Gołębiowska et al., 2017)[26].

At the time of completing work on this article, the new medium-term strategy had not yet been published. Regardless of its final shape, the experience of the years 2015-2023 should be drawn upon as material for institutional learning. The objective should not be the simple restoration of the SMPS or the mechanical transfer of earlier solutions, but the conscious use of accumulated experience in designing subsequent mechanisms for implementing state strategy. Jacobsson and Jałocha observe that "what influences the managerial decision about the direction of action [projectification or de-projectification] is the process of making sense of observed paradoxes, which move from latent paradoxes to salient paradoxes" (Jałocha, 2025). If the article is to be characterised as practice-informed recommendations, its fundamental recommendation is precisely this: that the concluded phase should not be treated as a closed chapter of history, but as a source of knowledge about the conditions, constraints, and possibilities of metagovernance in government administration.

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[26] At the same time, separating efficiency and legality in administrative action is an erroneous approach; cf. Gołębiowska et al., 2017, p. 63.

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ESG AND GREEN INNOVATION IN THE HOUSEHOLD CHEMICALS INDUSTRY: A CASE STUDY OF THE ALTAÏR GROUPE

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Purpose: The main objective of the research conducted for the purposes of this article was to identify the impact of the implementation of the ESG concept on the process of developing green innovations in a company from the household chemicals industry - the ALTAÏR Groupe
Design/methodology/approach: The study was exploratory and interpretive in nature. A qualitative case study approach was employed, supported by appropriate research methods: in-depth interviews, thematic analysis, and analysis of internal documents.
Findings: ESG serves as a strategic mechanism for managing corporate development at the ALTAÏR Groupe and is strongly linked to innovation processes. Green innovation is perceived as a response to the existing regulatory framework and stakeholder pressure. Key factors contributing to the development of green innovation include strong strategic leadership, interdepartmental collaboration, well-developed research and development competencies, organizational culture, organizational flexibility, and crisis situations. Barriers to innovation include resistance to change, high innovation costs, the ever-increasing number of regulations and their short implementation deadlines, and the imperative to reconcile high product effectiveness with the natural origin of ingredients.
Research limitations/implications: Due to the qualitative nature of the research conducted through a single case study, there is no basis for generalizing the conclusions to the entire industry. Therefore, further research is worthwhile, allowing both to deepen theoretical knowledge and to verify the obtained empirical results. In particular, an interesting avenue of scientific exploration seems to be the assessment of the impact of each ESG dimension (environmental, social, governance) on green innovation, conducted in a quantitative study covering a large group of companies in the household chemicals industry.
Practical implications: The article provides recommendations for managers and decision-makers in the studied industry.
Originality/value: This article expands knowledge on the implementation of green innovations in the household chemicals industry and identifies the mechanisms through which ESG principles support innovation.
Keywords: green innovation, household chemicals industry, ESG, thematic analysis, case study.
Category of the paper: Research paper, case study.

1. Introduction

Previous research does not provide a clear answer to the question of the relationship between the implementation of ESG (Environmental, Social, Governance) principles in a company and innovation. Some researchers argue that ESG practices have a positive impact on the development of innovation. They note that systematically assessing a company's ESG not only supports regulatory compliance and risk management but also acts as a catalyst for strategic, sustainable innovation (Dicuonzo et al., 2022; Zhou et al., 2023; Chen et al., 2023; Cabaleiro-Cerviño, Mendi, 2024; Tang, 2022; De Medeiros et al., 2022; Sanclaudio et al., 2025; Sun, Zhang, 2025; Li et al., 2023; Broadstock et al., 2020; Bothongo, Kinyar, 2025). ESG ratings facilitate the transition from symbolic to substantive green innovations (Zhang et al., 2024). This is crucial because pressure from environmental regulations often forces companies to passively implement symbolic green innovations, defined as "short-lived, adaptable, and rapid innovations". Fuente et al. (2022) found that ESG ratings allow investors to better understand managers' agency behavior, which helps reduce investor oversight costs and encourages companies to develop green technology innovations. There are also studies that are skeptical of ESG ratings in the context of green innovation. They conclude that implementing and disclosing ESG aspects can require significant capital investments and encourage greenwashing and public opinion manipulation (Liu et al., 2022; de Silva Lokuwaduge et al., 2022; Yoo et al., 2024).

The research findings cited above provide valuable insights into the relationship between ESG and green innovation, but they do not directly address the household chemicals industry. This industry not only plays a significant role in the global economy but is also undergoing significant changes in response to the Sustainable Development Goals (SDGs). Household chemicals companies remain under intense pressure from environmental regulations and the demand for organic and natural products. They face growing price competition and the growing importance of e-commerce, which necessitates the development of online sales while maintaining traditional sales channels (hypermarkets, supermarkets).

The overall goal of the research was to identify the impact of implementing the ESG concept on the development of green innovations at a household chemicals company, the ALTAÏR Groupe. The specific objectives are:

O1: Determining the role of ESG in the ALTAÏR Groupe management system.

O2: Exploring the impact of the environment (micro- and macro-) on the Group's ESG activities.

O3: Identifying the approach to innovation management at the ALTAÏR Groupe.

O4: Identifying factors supporting and barriers to the Group's innovation activities.

Four research questions were formulated to address the above objectives:

Q1: What role does ESG play in the ALTAÏR Groupe management system?

Q2: What is the impact of the environment (micro- and macro-) on the Group's ESG activities?

Q3: What is the innovation management process at the ALTAÏR Groupe?

Q4: What factors support and which constitute barriers to the Group's innovation activities?

The first part of the study presents a description of the household chemicals industry. The second part defines green innovations and presents the rationale for their development in the household chemicals industry. The following sections describe the research methodology, results and conclusions, and recommendations for improvement actions for the ALTAÏR Groupe.

2. General Description of the Household Chemicals Industry – Trends and Challenges

The household chemicals industry is an industrial sector engaged in the production and distribution of cleaning products, detergents, and hygiene products used in households, as well as in public facilities and restaurants. The main product categories include: laundry detergents (powders, capsules, liquids, and gels), cleaning products (dishwashing liquids, glass and floor cleaners, milk cleansers, and toilet cleaners), and home hygiene and care products (air fresheners, dishwasher tablets, and drain unblockers).

A report prepared by the Office of International Strategy and Analysis at PKO BP (2020) shows that in 2019:

- The United States was the largest market in the industry globally, with revenues of €22.3 billion, representing 16.3% of global sales.
- The highest revenues from sales of cleaning and laundry products, at €52.2 billion, were generated in Asia.
- Germany is the world leader in household chemicals exports, with a market share of 14.2%.
- Switzerland holds the top spot globally and in Europe in terms of per capita spending on laundry and cleaning products. Their average spending in 2019 was €76.50.

Data published on the Chemia i Biznes website (https://www.chemiaibiznes.com.pl) indicates that in 2024, the total value of the laundry, home cleaning, and professional hygiene products market in the region encompassing the EU-27, the United Kingdom, Switzerland, and Norway was €47.6 billion. The consumer segment (household care) accounted for €37.8 billion, while products and solutions for the professional sector (professional cleaning & hygiene) generated €9.8 billion. The largest product group was fabric care products (laundry

care), with a value exceeding €18 billion. The analyzed industry created 95,000 jobs in production plants and 360,000 jobs across the entire value chain. Household chemicals production was local and decentralized. There were approximately 700 production plants in Europe, 85% of which were small and medium-sized enterprises.

The industry is influenced by a complex set of external factors. In addition to macroeconomic indicators, which determine the overall health of the economy, regulatory frameworks, consumer preferences, and technological progress play a significant role. Governments around the world are tightening regulations on toxic substances, plastic packaging, chemical labeling, carbon dioxide emissions, and wastewater discharge. Consumers expect products that are effective yet safe for health and the environment. The industry is witnessing technological advances focused on sustainability, particularly the development of safe and environmentally friendly chemicals. Under these circumstances, the pursuit of sustainable development has become not only a moral obligation for companies in the analyzed industry but also the foundation for building a competitive advantage and strengthening their market position.

3. The Concept and Importance of Green Innovation and the Rationale for Its Creation in the Household Chemicals Industry

Green innovations address environmental challenges such as climate change, resource depletion, and environmental pollution (Marco-Lajara et al., 2023; Thomas et al., 2022; Martínez-Falcó et al., 2024; Kumar et al., 2025). Because they help reduce negative environmental impacts by optimizing resource use, minimizing waste, and conserving natural resources (Kumar et al., 2025; Desalegn, Tangl, 2022), they are crucial for the sustainable development of enterprises. It should be noted that the positive impact of green innovation on corporate sustainability is largely moderated by corporate governance practices (Bagh et al., 2024). Furthermore, agency problems cause state-owned enterprises to perform worse in terms of green innovation than private enterprises (Quan et al., 2025).

Green innovations may include: the development of environmentally friendly products (Thomas et al., 2022; Khan et al., 2023), the implementation of sustainable production methods (Thomas et al., 2022; Fei et al., 2016), the implementation of business strategies that integrate sustainability (Fei et al., 2016; Latif et al., 2025), as well as organizational changes supporting sustainable development (Fei et al., 2016). What distinguishes them is a long investment cycle, a high risk of failure and low rates of return (Zhang et al., 2024).

In the household chemicals industry, green innovations are based on the 12 principles of "green chemistry" developed by Paul Anastas and John Warner (1998). These principles include designing chemical products and processes that reduce or eliminate the production of

hazardous substances, using renewable resources, developing biodegradable products, and promoting energy efficiency.

The rationale for green innovation is widely discussed in the literature. Some researchers focus on societal pressure generated by various stakeholders, including governments, consumers, employees (Rayfield, Unsal, 2021), and institutional investors (Cheng et al., 2020). Governments around the world are tightening regulations on toxic substances, plastic packaging, chemical labeling, carbon dioxide emissions, and wastewater discharge. The European Union has been particularly active in legislation. The EU's comprehensive chemicals regulatory framework currently comprises approximately 40 pieces of legislation, including Regulation (EU) No. 1907/2006 on the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) and Regulation (EC) No. 1272/2009 on the Classification, Labeling, and Packaging of Hazardous Substances (CLP). The REACH regulation aims to control the use of potentially harmful chemicals in household products. This regulation is considered the most stringent in the world, generating significant – often negative – implications for production and distribution practices (Ujaczki, Backmann, 2026; Idahosa-Taylor, Collins, 2019).

In 2021, the Council of the European Union approved the Sustainable Chemicals Strategy (CSS). It aims to protect human health and the environment by minimizing the risks associated with chemicals throughout their life cycle. The CSS emphasizes the gradual phase-out of the most harmful chemicals, the promotion of safer alternatives, and the adoption of a circular economy approach to the production and use of chemicals. The latest regulation is Regulation (EU) 2026/405 of the European Parliament and of the Council on detergents and surfactants, published in March 2026. This document replaces the previous 2004 regulations and represents one of the most significant regulatory updates for the European cleaning products sector in the last two decades. The new regulations aim to enhance consumer protection, improve transparency of ingredient information, adapt regulations to technological advances – including the use of microorganisms in cleaning products – and introduce modern tools such as a digital product passport.

The evolving needs and expectations of consumers are crucial for the development of green innovations. Environmental awareness is increasingly leading consumers to prefer products perceived as non-toxic, sustainable, cruelty-free, and safe for children and pets. This is particularly evident among younger consumers and urban households. Increasingly concerned about the health impact of household chemicals, they often prioritize safety over product efficacy. Environmental awareness and values significantly influence willingness to pay for products with an eco-label (Jaheer Mukthar et al., 2026; Larashati, 2026). Negative factors that influence purchasing decisions include a lack of full knowledge of the chemicals contained in products (Glegg, Richards, 2007; Luchsinger, Bearth, 2026), the high cost, and limited availability of "green" products (Khalil et al., 2022; Glegg, Richards, 2007). It is worth noting that while European consumers focus on health and safety, in other regions of the world, cost

and efficiency remain priorities at the expense of environmental concerns (Luchsinger, Bearth, 2026).

Climate pressures and technological progress also attract the attention of researchers seeking the rationale for green innovations. Natural disasters are changing the perception of climate risk and stimulating pro-environmental actions (Choi et al., 2020; Maio, Popp, 2014; Elnahas et al., 2018; Alok et al., 2020).

The technological progress experienced by the industry is also significant. This is particularly true for the development of safe and environmentally friendly chemicals. The aforementioned EU Strategy for Sustainable Chemicals fundamentally shapes the approach to innovation in this industry, emphasizing that products must be "safe and sustainable by design" (Remonnay, 2025).

4. Methodology

The study adopted a qualitative paradigm, enabling the exploration of organizational processes, corporate culture, and practices related to ESG and innovation. This approach captures the complexity of the company context, industry conditions, and employee subjective experiences. It was exploratory and interpretive in nature, meaning it assumed multiple perspectives and contextualized phenomena. The research approach was an in-depth case study conducted at Groupe Altaïr, an organization in the household chemicals industry. The analysis included the company's ESG management mechanisms, the impact of the environment on ESG activities, the innovation management process, and the factors fostering and barriers to innovation.

The research subject was selected for its active implementation of ESG principles in daily production and R&D processes, its innovative activities, and its willingness to cooperate in a qualitative study. The selection of respondents was purposive, aimed at obtaining the richest possible information from individuals who are involved in ESG activities, participate in innovation processes, hold management positions, and are familiar with the procedures, processes, and mechanisms related to management within the company. A description of the respondents, along with their assigned codes (R1-R8), position, gender, length of service, and location, is provided in Table 1.

Table 1.
Characteristics of respondents

Respondent Code	Position	Gender M – male F – female	Seniority	Location PL – Poland FR – France
R1	CEO/President/Managing Director	M	30	FR
R2	Marketing & Innovation Director/Group Marketing Department	M	9	FR
R3	Chief Commercial Officer/CCO/Group Commercial Director	M	4	FR
R4	Brand and CSR Communication Manager/Group Marketing Department	F	9	FR
R5	Product Data & Codification Manager/Sales & Operations Planning Manager	M	9	FR
R6	Project Manager/Marketing Department	M	8	PL
R7	Regulatory Affairs Manager/R&D Department	F	20	FR
R8	*Director of R&D/Regulatory & Compliance Director*	F	7	FR

Source: own study based on conducted research.

The following research methods were used: in-depth interviews, thematic content analysis, and analysis of internal documents. The interviews were conducted between February and April 2026 in Poland and France. Eight interviews were conducted, each lasting approximately 60 minutes. The analysis of internal documents utilized ESG and CSR policies, environmental reports, operational procedures, R&D documents, audit and certification reports.

5. Results

5.1. Description of Groupe Altaïr

Groupe Altaïr is a French industrial and commercial entity operating in the household chemicals sector, producing cleaning and household care products. The company was founded in Lille, France, in 1946. It currently operates internationally. The organizational structure is based on a model of distributed business units (Business Units) operating in various countries, including France, Poland, Spain, the Netherlands, and Belgium. This solution allows for the simultaneous maintenance of strategic coherence and the adaptation of operational activities to the specifics and requirements of local markets. Production processes are carried out in specialized industrial plants located in France (two facilities) and Spain (one facility).

The group's core business is the development, production, and distribution of chemical products, including cleaning agents, surface care products, renovation products, and biocides. The scope of operations encompasses production processes (including the production of liquid, aerosol, and specialty products) as well as packaging, logistics, and international supply chain management. A key element of Groupe Altaïr's business is the creation and development of brands across various product categories, with key brands including Starwax, Briochin,

Marcel's Green Soap, and KPro. The company's portfolio encompasses over three thousand products, enabling it to tailor its offerings to diverse consumer groups and specific applications, encompassing both traditional solutions and products with a reduced environmental impact. Additionally, the company develops lines of eco-friendly products certified by Ecocert and EU Ecolabel, confirming their compliance with stringent environmental and consumer safety standards. The Group's products are distributed in 45 countries, with the European market remaining its primary focus. The Groupe employs approximately 490 people and its annual revenues in 2025 reached €190 million (Altaïr Groupe, *ALTAIR Rapport RSE, 2026*, p. 3, company document, 2026).

An important direction of the company's development is the integration of sustainable development principles into its operational and strategic activities. This approach encompasses actions aimed at reducing the negative impact of its operations on the environment, including reducing CO_2 emissions, optimizing the use of raw materials, increasing the share of recycled materials, and eliminating potentially harmful substances (Altaïr Groupe, *Substances Policy*, 2024). At the same time, social and governance aspects related to accountability to stakeholders and transparency are taken into account. The company's sustainable development strategy is based on three fundamental pillars: Planet, Employees, and Consumers. In the Planet area, activities focus on reducing the negative impact of operations on the climate and natural resources, in particular by reducing CO_2 emissions and improving the environmental profile of products. The Employees pillar emphasizes the role of working conditions, developing competencies, and fostering engagement. In the Consumers area, the importance of product safety, quality, and information transparency is emphasized (Groupe Altaïr, *CSR Report* ,2024; Groupe Altaïr Manifesto: Corporate Social Responsibility. Our Commitments to Sustainable Development. Internal Company Document, 2024).

In the Groupe Altaïr management model, ESG does not function as a separate area of activity, but as an integrated element within core organizational processes. In the environmental area, particular importance is attached to reducing the carbon footprint across the entire value chain (scopes 1, 2, and 3), in line with international decarbonization guidelines, including the Science Based Targets initiative (SBTi) approach (Brunel SAS, *CLIM'ACT - réunion du 041125*, internal company document, 2025). In governance, formalized management mechanisms play a significant role, including codes of conduct (Groupe Altaïr, *Code of Conduct for Commercial Relations*, internal company document, 2022), compliance procedures, and internal control systems, including whistleblowing solutions and anti-corruption policies (Groupe Altaïr, *Code of Conduct for Anti-Corruption FR*, internal company document, 2022). In the social area, organizational culture and human capital development are at the forefront.

The company's operations emphasize the operationalization of ESG goals through the use of measurable indicators (KPIs) and analytical tools. Particular importance is attached to solutions that enable the assessment of the environmental impact of products throughout their

entire life cycle, such as the Green Impact Index. These tools support decision-making processes and enable the incorporation of environmental criteria into product design.

The company's innovation activities encompass both product and process innovations. Key areas of activity include the development of more environmentally friendly product formulas and the elimination of selected chemical substances (e.g., through the use of internal lists of restricted ingredients), increasing the share of recycled materials in packaging, and reducing the use of plastics. Implementing logistics solutions aimed at reducing emissions (e.g., intermodal transport and optimizing logistics operations) as well as the digitalization of operational processes, including reducing the use of paper documentation, are also crucial.

5.2. Thematic analysis

Thematic analysis is the process of systematically transforming qualitative textual data (conversation transcripts) into measurable or structured findings. This method allows for the identification of key themes, emotions, and opinions and is widely used in scientific research. After transcribing the interviews, eliminating irrelevant information, and selecting key fragments (so-called meaning units), thematic analysis was conducted, consistent with the approach of Braun and Clarke (2024). This included the following steps: 1) Familiarization with the material; 2) Data coding; 3) Grouping codes into themes; 4) Identifying relationships between themes; 5) Interpretation and inference; 6) Creating a research narrative.

The analysis resulted in the identification of eight "Themes" and their associated "Codes". The respondents' statements were subjected to "Interpretation and inference" (see Table 2).

Table 2.
Topics identified through thematic analysis, along with interpretation of statements and conclusions

No.	Topic	Main Codes	Interpretation and Inference
1.	ESG as a strategic business imperative	• The strategic role of ESG, • Competitive advantage, • Long-term value, • Integrating ESG into corporate strategy, • Responsible development.	One of the most common themes is the perception of ESG not as a formal requirement, but as a strategic element of building competitive advantage. Respondents indicate that ESG activities are increasingly integrated into decision-making processes and organizational development. R1 emphasizes that "...regulatory pressure in Poland is relatively limited, while companies impose high standards of responsibility on themselves". R2 shares a similar view, pointing out that "ESG has become an integral element of the company's CSR strategy and long-term development". According to R3, ESG activities serve as a "strategic filter" through which market signals are interpreted and investment decisions are made.
2.	Measurement and monitoring of the effects of activities in areas E, S and G	• ESG measurement, • environmental indicators, • carbon footprint, • Green Impact Index, • SBTi.	To measure environmental performance, the company utilizes tools such as the Green Impact Index, Science Based Targets Initiative (SBTi), carbon footprint analysis, ESG audits, scorecard systems, and Ecocert and Ecolabel certifications. Of particular importance is the Green Impact Index, which evaluates products in terms of CO_2 emissions, resource consumption, impact on biodiversity, and overall environmental impact.

Cont. table 2.

3.	Growing stakeholder pressure as a catalyst for ESG transformation	• customer pressure, • consumer expectations, • retail chain requirements, • ESG audits, • ESG scoring, • transparency.	ESG is becoming a mechanism for coordinating relationships across the entire value chain. Stakeholder requirements provide a significant impetus for implementing green innovations and organizational changes. The strongest pressure comes from customers and retail chains. Respondents point to companies such as Carrefour, Castorama, Rossmann, and Leroy Merlin as organizations requiring increasingly advanced environmental data and compliance with specific ESG standards. Growing consumer awareness is also a recurring theme. Consumers expect natural products, biodegradable formulas, recycled packaging, and transparency of ingredients. Respondents note that customer requirements are increasingly taking the form of formal ESG rating systems. These systems influence purchasing decisions and business relationships.
4.	Regulations as a source of innovation	• regulatory compliance, • product reformulation, • eco-design, • regulations as a driver of development, • technological adaptation.	Regulations are perceived not only as constraints but also as a source of innovation. The most frequently cited legal acts include REACH, CLP, biocidal products regulations, packaging and recycling regulations, the Green Claims Directive, the AGEC Act, and regulations on emissions and carbon footprints. Respondents emphasize that the need to adapt formulations, packaging, and production processes leads to the search for new technological solutions. Respondents R7 and R8, in particular, point out that the shortening deadlines for implementing new regulations require faster adaptation processes and the development of organizational competencies.
5.	Green innovation as a combination of efficiency and environmental responsibility	• green innovation, • eco-innovation, • product innovation, • process innovation, • environmental responsibility.	The Altaïr Groupe has developed a "green innovation" model in which environmental criteria are an integral element of the innovation process, not an additional requirement. Respondents define innovation much more broadly than just introducing new products. Innovations include: new product formulas, packaging solutions, production process improvements, organizational changes, digital tools, and new business models. Innovation is characterized by a strong link between environmental aspects. According to R3, "...innovation means creating solutions that are technically effective and environmentally responsible". Respondents emphasize the need to maintain a balance between product effectiveness, safety, the natural origin of ingredients, and environmental impact.
6.	Systematic management of ESG innovations	• Project management, • Innovation committee, • Stage-Gate process, • Environmental assessment, • ESG validation.	The analysis indicates a high degree of formalization in the new product development process. It encompasses stages such as market needs identification, feasibility analysis, research and development, environmental assessment, technical validation, economic evaluation, and industrial implementation. The innovation committee and the Stage-Gate process play a significant role. A particularly important element is the mandatory assessment of the environmental impact of products prior to their launch.

Cont. table 2.

7.	Factors contributing to the creation of green innovations	• Strategic orientation, • Interdepartmental collaboration, • Interdisciplinarity, • Research, development, and technological competencies, • Organizational culture, • Organizational flexibility, • Crises.	The most important factor driving innovation is the integration of ESG into a company's strategy. Collaboration between departments such as Marketing, R&D, Regulatory Affairs, Procurement, Sales, Finance, Production, and Logistics is crucial. Interdisciplinarity allows for simultaneous consideration of market, environmental, technological, and economic requirements. Employee engagement, openness to new solutions, and a willingness to take risks are crucial. R2 and R3 emphasized the importance of communication and an organizational culture that fosters experimentation and learning. Respondents point to the Group's significant research and development potential, including its own laboratories, formula development, and the ability to co-create products with suppliers. The Group's technological competences enable rapid adaptation to new trends and regulations. Respondents emphasize that the Group's medium size provides it with organizational flexibility and allows for more effective implementation of new solutions than large corporations. An interesting finding from the research is the perception of crisis situations (COVID-19, the war in Ukraine, inflation) as factors that motivate the search for new solutions and increase the organization's ability to adapt.
8.	Barriers to the development of green innovations	• resistance to change, • costs of innovation, • regulatory barriers, • technological barriers.	Respondents identified a number of factors limiting the development of green innovations. The most frequently cited barriers include: organizational barriers (resistance to change, limited human resources, process complexity), economic barriers (high product reformulation costs, pressure on short-term financial results, customer price sensitivity), regulatory barriers (growing number of regulations, short implementation timelines, lengthy certification procedures), and technological barriers (difficulty reconciling product effectiveness with the natural origin of ingredients, limited availability of certain raw materials).

Source: own study based on conducted research.

6. Synthetic Conclusions and Recommendations

The collected empirical material provided answers to four research questions. The Altaïr Groupe case study can serve as an example of a company's transformation toward a sustainable operating model. Both the analysis of organizational documentation and the thematic analysis indicate that ESG serves as a strategic mechanism for managing the company's development at the Altaïr Groupe. Furthermore, it is strongly linked to innovation processes, guiding the development of products, processes, and stakeholder relationships. ESG is becoming a mechanism for coordinating relationships throughout the value chain. Stakeholder requirements provide a significant impetus for implementing green innovations and organizational changes. The strongest pressure comes from regulators, retail chains, and consumers. The new product development process is highly formalized within the Group.

It includes stages such as market needs identification, feasibility analysis, research and development, environmental assessment, technical validation, economic assessment, and industrial implementation. The Innovation Committee and the Stage-Gate process play a significant role. Key factors contributing to the development of innovation include: strong strategic leadership, cross-departmental collaboration, well-developed R&D competencies, organizational culture, and organizational flexibility. Barriers include: resistance to change, high innovation costs, and regulatory and technological barriers.

The Altaïr Groupe is an example of a sustainable business model in which ESG serves as a strategic catalyst for innovation. Further improvement in the Group's ability to create green innovations in the context of its sustainable development strategy could include:

First: Strengthening the Open Innovation System - Respondents indicate that most innovations are developed internally or with suppliers. Expanding the collaboration network could increase the diversity of knowledge sources. It is worthwhile to expand collaboration to include universities, R&D units, cleantech startups, and organizations focused on the circular economy. This will increase access to breakthrough technologies and shorten the time to commercialization of new solutions.

Second: Expanding the ESG foresight system - The regulatory framework in the industry is constantly growing in complexity. Respondents believe that the short timeframe for implementing new regulations poses a significant challenge. Therefore, it is recommended to create a formal ESG foresight system, encompassing: analysis of future legislative changes, market development scenarios, analysis of low-emission technologies, and identification of future consumer expectations.

Third: Development of ESG competencies across the organization - One of the most frequently cited barriers to innovation was the resistance to change among some employees. Therefore, despite the high level of ESG awareness among management, it is worthwhile to systematically develop the competencies of employees at all levels. This can be achieved through ESG training, ESG ambassador programs, workshops on green innovations, or an employee idea submission system.

7. Conclusion

The conducted research enabled the achievement of the established research objectives. The role of ESG in the ALTAIR Group's management system was defined, the impact of the environment on the Group's ESG activities was demonstrated, and the innovation management method was identified, as well as the factors contributing to and barriers to the ALTAIR Group's innovation activity. Due to the qualitative nature of the research conducted through a single

case study, there is no basis for generalizing the conclusions to the entire industry. Therefore, further research is worthwhile, allowing both to deepen theoretical knowledge and to verify the obtained empirical results. In particular, an interesting avenue of scientific exploration seems to be the assessment of the impact of each ESG dimension (environmental, social, governance) on green innovation, conducted in a quantitative study covering a large group of companies in the household chemicals industry.

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THE IMPACT OF ESG GOVERNANCE ON INNOVATION IN A HOUSEHOLD CHEMICALS COMPANY: THE MODERATING ROLE OF DYNAMIC CAPABILITIES

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Purpose: The main aim of the article was to identify and assess the mechanisms linking ESG governance with dynamic capabilities and innovations in a company operating in the household chemicals industry - ALTAÏR Groupe
Design/methodology/approach: The study was exploratory and interpretive in nature. The research strategy employed was an in-depth case study of an organization in the household chemicals industry – GROUPE ALTAÏR. Data triangulation was achieved using two complementary qualitative methods: in-depth interviews (IDI) and internal document analysis. The collected data were subjected to content analysis.
Findings: Research indicates that ESG governance does not directly influence innovation, but rather acts as a system of rules, filters, and criteria that triggers a chain of dynamic processes: sensing → seizing → reconfiguring. Only the reconfiguration process—including product redesign, process restructuring, formalization of new ESG structures, transformation of supplier relationships, and implementation of sustainable technologies—materializes previously identified and exploited opportunities in the form of innovation. This means that reconfiguring acts as a direct mediator between resource mobilization (seizing) and innovation outcomes, completing the mechanism consistent with the classic approach to dynamic capabilities.
Research limitations/implications: Due to the qualitative nature of the research conducted through a single case study, there is no basis for generalizing the conclusions to the entire industry. Future research should focus on validating the proposed ESG management–dynamic capabilities–innovation model in a broader organizational context. In particular, case studies and quantitative studies using structural equation modeling could confirm the mediating role of sensing, capturing, and reconfiguration capabilities. Longitudinal studies would also be valuable for examining the temporal and sequential nature of the identified chain reaction mechanism, whereby ESG governance stimulates sensing capabilities, which then trigger the processes of capturing, reconfiguration, and innovation.
Practical implications: The article provides recommendations for managers and decision-makers in the studied industry.
Originality/value: The article broadens the knowledge on the importance of ESG governance and dynamic capabilities for the development of innovation in a household chemicals company.

Keywords: dynamic capabilities, ESG governance, innovation, household chemicals industry, content analysis.
Category of the paper: Research paper, case study.

1. Introduction

Studies conducted across industries and regions confirm a strong, positive relationship between ESG performance and corporate innovation (Wu L. et al., 2025; Wu Y. et al., 2025, Van et al., 2025). Companies with higher ESG scores invest more in R&D, generate more patents, and achieve better sustainability performance (Dicuonzo et al., 2022; Zhou et al., 2023; Chen et al., 2023; Cabaleiro-Cerviño, Mendi, 2024; Tang 2022; De Medeiros et al., 2022; Sanclaudio et al., 2025; Sun, Zhang, 2025; Li et al., 2023; Broadstock et al., 2020). This relationship is particularly strong in manufacturing and other industries with a high environmental impact. Reasons for this include:

- Financial mobilization and access to resources: ESG practices help companies mitigate financial constraints, attract investment, and access the resources necessary for innovation (Tang, 2022; Li et al., 2023; Chen et al., 2023; Wang, Wang, 2024; Xu et al., 2026; Li et al., 2024).
- ESG governance and internal controls: Effective ESG governance and internal controls increase both the quantity and quality of innovation (Sanclaudio et al., 2025; Sun, Zhang, 2025; Wang, Wang, 2024).
- Stakeholder Engagement: ESG-driven companies are more responsive to stakeholder needs, leading to systematic innovation (Cabaleiro-Cerviño, Mendi, 2024; Lee, 2025).
- Supply Chain Collaboration: High ESG performance in customer companies increases the effectiveness of eco-innovation among suppliers, strengthening sustainability throughout the value chain (Huang et al., 2025).

Ownership structure and regulatory frameworks moderate the ESG-innovation relationship. The impact of ESG on innovation is stronger in family firms than in firms with other ownership structures (Sanclaudio et al., 2025; Sun, Zhang, 2025) and in regions subject to significant environmental regulations (Wang, Wang, 2024; Bothongo, Kinyar, 2025). Dynamic capabilities, defined as a firm's ability to adapt to a changing environment and integrate new knowledge, are also a significant moderator of this relationship. Generally, firms with higher dynamic capabilities achieve better ESG and innovation performance (Wang, Zang, 2026; Liang et al., 2025). Consumer preferences for sustainable products may motivate firms to innovate in line with ESG principles, further reinforcing the importance of dynamic capabilities in this context.

The research findings cited above provide valuable insights into the broader relationship between ESG governance, innovation, and dynamic capabilities, but they do not directly apply to the household chemicals industry. Meanwhile, this industry is undergoing significant changes in response to the Sustainable Development Goals (SDGs). Changing consumer preferences and increased regulatory activity are leading industry players to increasingly perceive green innovation as a way to avoid future compliance costs, reduce legal and reputational risk, differentiate products, and build customer loyalty.

Given the importance of the household chemicals industry to the global economy and its transformation toward sustainable development, it is justified to undertake research to understand the mechanisms of innovation in this industry, particularly the moderating role of dynamic capabilities between ESG governance and innovation.

The research problem was formulated as the following question: *What mechanisms link ESG governance with dynamic capabilities and innovation in the household chemicals company Groupe Altaïr?*

The general objective of this article is to identify and assess the mechanisms linking ESG governance with dynamic capabilities and innovation in a household chemicals company. Specific objectives are:

O1: Identifying the impact of ESG governance on Groupe Altaïr's dynamic capabilities.

O2: Diagnosing the mechanisms of the links between ESG governance, dynamic capabilities, and the process of creating and implementing innovation.

The research questions were formulated accordingly:

Q1: How does ESG governance influence Groupe Altaïr's dynamic capabilities?

Q2: What mechanisms link ESG governance, dynamic capabilities (sensing, seizing, reconfiguring processes), and innovation?

The following section highlights the importance of ESG and dynamic capabilities for the company's innovation. The research methodology, results, and conclusions are then described.

2. The importance of ESG and dynamic capabilities for enterprise innovation

Researchers' opinions on the role of ESG in innovation are divided. Some view this role positively, pointing out that ESG assessment not only supports regulatory compliance and risk management but also acts as a catalyst for strategic, sustainable innovation, enabling companies to improve their competitiveness and resilience (Dicuonzo et al., 2022; Zhou et al., 2023; Chen et al., 2023; Cabaleiro-Cerviño, Mendi, 2024; Tang, 2022; De Medeiros et al., 2022; Sanclaudio et al., 2025; Sun, Zhang, 2025; Li et al., 2023; Broadstock et al., 2020; Bothongo, Kinyar, 2025). ESG ratings provide a company with market connectivity, help reduce information

asymmetry between the company and external stakeholders, and stimulate the adoption of green technology innovations. Rayfield and Unsal (2022) analyzed the relationship between the creation of green patents by companies and environmental violations. Their study found that companies that violate environmental regulations tend to prioritize the creation of green patents in the long run. The high legal costs associated with environmental violations, as well as the associated reputational damage, may encourage companies to implement more green innovations.

There are also studies that present a skeptical stance towards ESG assessments in the context of green innovation. They conclude that implementing and disclosing ESG aspects facilitates greenwashing and public opinion manipulation and may require significant capital investments (Liu et al., 2022; de Silva Lokuwaduge et al., 2022; Yoo et al., 2024). Furthermore, innovation is undermined by excessive or inconsistent ESG activities (Broadstock et al., 2020; Lan, Zhou, 2024; Liu, Wang, 2025; Wu et al., 2025), as well as inadequate corporate governance practices (Amore, Bennedsen, 2016).

For organizations to thrive in a rapidly changing environment, they must possess dynamic capabilities. Teece (2007) divided dynamic capabilities into three repeatable, key strategic processes (so-called microfoundations):

- sensing – the ability to scan the environment and detect opportunities/risks; this includes monitoring regulations, analyzing market and environmental trends, and identifying new technologies;
- seizing – the ability to mobilize resources in response to identified opportunities; this includes making decisions about how to respond to ESG requirements, launching R&D projects, and reallocating resources to new initiatives;
- transformation – the ability to reorganize resources, structures, and processes; this includes, among other things, changing production processes, reorganizing departments, implementing sustainable technologies, and modifying product formulas.

The dynamic capabilities theory arose as a response to the limitations of the RBV (Resource-Based View) model, a resource-based approach to strategic management that assumes that the key to achieving sustainable competitive advantage lies in a firm's internal resources and competencies, not in analyzing the market environment. Dynamic capabilities emphasize the processes and activities that enable firms to renew resources and adapt to environmental changes (Bao-jie, 2010; Dasgupta, Sanyal, 2019; Altintas, 2025). This theory emphasizes the importance of innovation and the ability to organize resources to create new opportunities (Ahmadi, Arndt, 2022; Shevchenko et al., 2020). It assumes that firms must not only possess resources but also develop the ability to transform them in response to market dynamics (Tallman, 2015; Cavusgil, Deligonul, 2024).

Dynamic capabilities significantly influence innovation processes in organizations, especially in dynamically developing industries. They allow companies to recognize opportunities, seize them, and transform their operations accordingly (Hongjia, Bin, 2025;

Jácome et al., 2022). Companies that effectively manage their dynamic capabilities can quickly implement new technologies and innovate their product offerings (Gazzola, 2018; Kien et al., 2016; Fainshtein et al., 2024). The ability to continuously reconfigure resources allows companies to maintain competitive advantage by promoting a culture of incremental and breakthrough innovation (Jácome et al., 2022; Gazzola, 2018). Dynamic capabilities play a key role in increasing a company's competitive advantage. They enable organizations to create and protect intangible assets that contribute to long-term performance (Teece, 2007; Altintas, 2025). Companies with well-developed dynamic capabilities can not only adapt to change but also shape their business ecosystems through innovation and collaboration (Teece, 2007; Cadrazco-Parra et al., 2020). Xu et al. (2025) analyzed how ESG practices contribute to organizational resilience through the mediating role of dynamic capabilities and the moderating effect of embeddedness in social networks, achieved through board members' social capital. The study found that ESG effectiveness significantly enhances firms' dynamic capabilities, thus strengthening their resilience to external shocks. A stronger position in board members' social networks strengthens the link between ESG and dynamic capabilities.

The development of dynamic capabilities can be achieved by investing in the development of employees' skills and knowledge (Altintas, 2025; Jácome et al., 2022), encouraging them to cooperate cross-functionally (Tallman, 2015; Cavusgil et al., 2024) or finally implementing processes that support quick decision-making and resource reconfiguration (Fainshtein et al., 2024; Leyva-Tapia et al., 2024).

3. Methodology

The research conducted for this study adopted a qualitative paradigm, enabling the exploration of practices related to ESG, dynamic capabilities (sensing, seizing, reconfiguring), and innovation. This approach captures the complexity of the corporate context, industry conditions, and employee subjective experiences. The study was exploratory and interpretive in nature, assuming multiple perspectives and contextual determinants of phenomena. The research strategy employed was an in-depth case study.

Research Subject

The study was conducted at an organization in the household chemicals industry – GROUPE ALTAïR. The choice of this entity was justified not only by the active implementation of ESG principles in daily operations, but also by the high degree of integration of corporate governance with the company's management and development processes.

An additional argument in favor of this company is its systematic research and development activities, enabling the observation of the impact of ESG practices on the process of generating and implementing innovation. The analyzed entity combines the achievement of business goals with responsible management, which creates the opportunity to identify mechanisms through which governance principles support the creation of new product, organizational, and technological solutions.

Access to management staff with knowledge of the company's management processes, ESG strategy, and innovation activities was also crucial. This ensured the ability to obtain in-depth qualitative data necessary to achieve the research objectives. The choice of GROUPE ALTAÏR can therefore be considered purposeful and consistent with the assumptions of selecting a typical case, enabling a detailed analysis of the relationship between ESG governance and the company's innovation performance.

Groupe Altaïr is a French industrial and commercial company operating in the household chemicals sector, founded in Lille, France, in 1946. It currently sells products in 45 countries, with the European market remaining its primary area of activity. Groupe Altaïr employs approximately 490 people and its annual revenues in 2025 were estimated at €190 million (Altaïr Group, ALTAIR Rapport RSE, 2026). The organizational structure is based on a model of distributed business units (Business Units), operating in various countries, including France, Poland, Spain, the Netherlands, and Belgium. Production processes are carried out in specialized industrial plants located in France (two facilities) and in Spain (one facility).

The group's core business is the development, production, and distribution of chemical products, including cleaning agents, surface care products, renovation products, and biocides. Groupe Altaïr's main brands are Starwax, Briochin, Marcel's Green Soap, and KPro.

An important direction of the company's development is the integration of sustainable development principles into its operational and strategic activities. This approach encompasses activities aimed at reducing the negative impact of its operations on the environment, including reducing CO_2 emissions, optimizing the use of raw materials, increasing the share of recycled materials, and eliminating potentially harmful substances (Altaïr Group, Substances Policy, 2024). Social and organizational aspects related to accountability to stakeholders and operational transparency are also taken into account.

Selection of respondents

The selection of respondents was purposive, aimed at obtaining the richest possible data. The respondents were people who are involved in ESG activities, participate in innovation processes, hold managerial positions, are familiar with procedures, processes and mechanisms related to management in the company and are able to describe specific innovation implementation processes (see Table 1).

Table 1.
Characteristics of respondents R1-R8

Respondent Code	Position	Gender M – male F – female	Seniority	Location PL – Poland FR – France
R1	CEO/President/Managing Director	M	30	FR
R2	Marketing & Innovation Director/Group Marketing Department	M	9	FR
R3	Chief Commercial Officer/CCO/Group Commercial Director	M	4	FR
R4	Brand and CSR Communication Manager/Group Marketing Department	F	9	FR
R5	Product Data & Codification Manager/Sales & Operations Planning Manager	M	9	FR
R6	Project Manager/Marketing Department	M	8	PL
R7	Regulatory Affairs Manager/R&D Departmen	F	20	FR
R8	Director of R&D/Regulatory & Compliance Director	F	7	FR

Source: Own work.

The study was based on triangulation of data sources. Two complementary qualitative methods were used: in-depth interviews (IDI) and analysis of internal documents (ESG and CSR policies, environmental and quality reports, operational procedures, R&D and innovation documents, audit and certification reports).

The primary method of data collection was interviews. Between February and April 2026, eight interviews were conducted with CEOs and senior and middle managers. Each interview lasted approximately 60 minutes. The interview script included a set of questions, including:

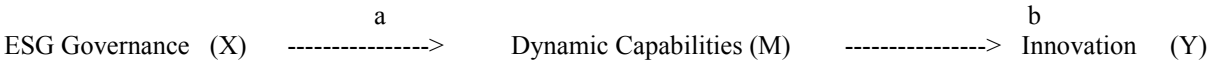
1) Personality questions (position held, tenure at the company, location).
2) ESG governance (ESG-related policies, procedures, standards, the role and responsibility of the board, and the impact of the micro- and macro-environment on ESG activities).
3) Dynamic Capabilities (Sensing – monitoring the environment, identifying signals and trends, responding to signals; Seizing – making decisions in response to ESG requirements, allocating resources; Reconfiguring – reorganizing, changing processes and technologies influenced by ESG).
4) Innovation (types of innovation, innovation process, effects of innovation).

Six interviews were conducted in English, two in Polish. The interview script was pilot-tested to ensure the terminology was understandable to the interviewees. Additionally, the main research constructs, i.e., ESG governance, dynamic capabilities, sensing, seizing, and reconfiguring, were explained during each interview. To ensure the quality of the empirical data, a multi-stage review of the interview transcription and translation process was conducted. The transcripts were verified by comparison with the source recordings. They were then translated from English into Polish, preserving the contextual meaning of the statements. Selected excerpts were also back-translated, which allowed for an assessment of the semantic consistency of the translations with the respondents' original statements.

To ensure the ethical nature of the study, consent was obtained from the company to collect data, participants were anonymized, sensitive data was not disclosed, and respondents were assured of the right to withdraw from the interviews at any stage. The recordings and transcripts obtained during the interviews are stored in a folder on a password-protected company computer.

Description of the Theoretical Model

The theoretical model adopted in this study assumed that ESG governance (X) influences innovation (Y) indirectly through the development of dynamic capabilities (M). This increases the need to seek information (sensing), requires rapid response (seizing), and forces the reconfiguration of resources (reconfiguring). The model assumes the mediation of dynamic capabilities in the ESG governance → innovation relationship (Figure 1).



Legend:
a: Impact of ESG governance on dynamic capabilities
b: Impact of dynamic capabilities on innovation
a*b: Indirect effect (mediation)

Figure 1. Mediation diagram.

Source: Own work.

"ESG governance" in the model refers to the part of corporate governance focused on managing environmental (E) and social (S) aspects, as well as corporate governance (G). It encompasses activities through which a company ensures accountability, transparency, and ethical conduct in managing its environmental and social impacts, as well as its finances. It combines classic corporate governance principles with broader sustainable development goals. The main aspects of ESG governance and their corresponding practices are presented in Table 2.

Table 2.
Main aspects of ESG governance and corresponding practices

ESG Governance Aspects	Example Practices
ESG Governance Structure	• Designating individuals/teams responsible for ESG. • Clearly allocating roles and responsibilities for achieving ESG goals within the organization.
ESG/Sustainability Strategy	• Setting goals and priorities in environmental, social, and governance areas. • Integrating the ESG/SR strategy with the business strategy.
ESG Policies/ Procedures/ Standards	• Environmental policies (e.g., CO_2 emission reduction, waste management). • Social policies (diversity, employee rights, relations with the local community). • Management ethics (anti-corruption policy, codes of ethics).
Monitoring and Reporting	• Measuring the effectiveness of ESG activities. • ESG reports for key stakeholders. • Audits and external assurance.

Cont. table 2.

ESG Compliance and Risk Management	• **Identification and assessment of environmental, social, and governance risks.** • **Risk mitigation action plans.**
Stakeholder Engagement	• Dialogue with key stakeholders. • Incorporating stakeholder opinions into strategic decisions.
Organizational Culture	• Implementing ESG values/principles/standards in the company's daily operations.

Source: Own work.

Data collected through in-depth interviews were subjected to content analysis according to Braun and Clarke (2024). This analysis comprised eight stages:

Stage 1: Transcription: Careful transcription of interview recordings, anonymization of data.

Stage 2: Preliminary reading and notes: First review of all transcripts, creation of analytical memos, and preliminary identification of themes and recurring themes.

Stage 3: Open coding: Assigning data fragments to preliminary descriptive codes.

Stage 4: Deductive coding: Organizing codes, consolidating duplicate codes.

Stage 5: Axial coding: Analysis of relationships between codes. Step 6: Selective Coding: Creating the main narrative themes.

Step 7: Data Triangulation: Comparison of data and information obtained through interviews and analysis of organizational documentation.

Step 8: Building the Research Narrative (Reporting): Writing down conclusions, presenting mediation mechanisms, illustrating process quotes (thick description), and answering the following questions: How does ESG shape dynamic capabilities? How do dynamic capabilities influence innovation? What does this look like in the specific context of the household chemicals industry?

4. Results

Through selective coding (Step 6), six main narrative themes emerged (Table 3), highlighting the roles played by ESG governance in the context of the surveyed company's innovation activities. Content analysis of the interviews indicates that ESG governance shapes the quality of management processes, transparency, strategic orientation, and a company's readiness to respond to environmental and social challenges. Strong ESG governance leads to the strengthening of dynamic capabilities, as it enhances an organization's ability to: detect changes in regulations, technology, and stakeholder expectations (sensing), transform environmental signals into investment decisions, set priorities, mobilize resources (seizing), and, ultimately, reconfigure products, processes, structures, and relationships with partners (reconfiguring). In turn, dynamic capabilities foster innovation.

Table 3.
Main themes of the narrative

Topic	ESG Governance Elements	Dynamic capability as a mediator	Intermediary activities	Innovations	Respondent Statements
ESG as a filter for market interpretation	ESG objectives, ESG KPIs, Green Impact Index, SBTi (Science Based Targets Initiative), customer expectations	Sensing	Monitoring customers, regulations, and environmental trends	Eco-friendly recipes, new packaging, plastic-free/ refill products	R1: "The greatest pressure comes from customers. We work with large European groups, such as Castorama, Carrefour, and Rossmann, which have their own strong ESG policies. We feel the pressure from them and see that they care about us being well-regarded in this area". R4: "ESG acts as a strategic filter". R5: ESG enables the company to prioritize sustainable solutions in its decision-making process. R8: "The most important environmental signals are the SBTi project, which aims to reduce emissions, and the Green Impact Index, an indicator that demonstrates the company's environmental protection efforts towards consumers".
ESG as a criterion for project selection	Formalization of decisions, innovation committee, ESG KPIs, risk analysis	Seizing	Environmental scoring, business case, project goals, prioritization	Fewer innovations, but more significant, ESG-compliant ones	R2: "All innovations and product improvements must align with these three pillars. At the same time, innovation projects must deliver economic benefits to support the company's growth and long-term development". R3: "At each stage, the project is assessed based on performance, profitability, financial viability, and ESG contribution". R6: "ESG ensures that decisions are analyzed not only in terms of profitability, but also environmental compliance and the impact on the company's long-term image".
ESG as an impulse for product reconfiguration	Compliance, chemicals policy, LCA, certifications	Reconfiguring products	Reformulation, elimination of toxic substances, increasing the share of recyclate, life cycle assessment	Natural products, Ecolabel/ Ecocert, recycled packaging	R5: "The latest innovations include: new production workshop and development of ECOLABEL/eco-friendly product recipes, recycled or lighter packaging, new raw materials".

Cont. table 3.

ESG as an impulse for process reconfiguration	**Emission reduction, responsible sourcing, audits, transparency**	**Reconfigu-ring processes**	**Multimodal transport, change of suppliers, digitalization of documents, dosing optimization**	**Reducing waste, emissions, costs, increasing efficiency**	**R1: "We use a dedicated application, and most of our document flow is electronic. This saves paper, time, and energy. In recent years, solutions such as hybrid systems and investments in carports with solar panels have also emerged, which reduce energy consumption from external sources". R6: "We have implemented the ClickUp project and task management system, which streamlines communication and allows for monitoring task completion".**
ESG as a mechanism for cooperation	Stakeholder relations, partnerships, suppliers	Seizing + reconfiguring relationships	Co-creation, co-branding, supplier selection, collaboration with laboratories	Open innovation,	R2: "...we have innovations developed internally, utilizing our laboratories and industrial capabilities. Secondly, we have co-creation with suppliers, where we ask them to develop a product for us because they have specialized knowledge. Thirdly, we have co-branding, where a partner has a good product and we contribute our commercial capabilities, so we develop together". R8: "The company is looking for partnerships aimed at reducing its carbon footprint".
ESG governance as a mechanism for shaping the quality of decisions	Management accountability, audits, reporting, compliance	Seizing	Additional reflection, environmental and regulatory risk analysis	innovations are introduced slowly but have high value	R3: "…ESG credibility takes years to build and can be lost very quickly. Therefore, decisions must balance economic pressures with long-term sustainability commitments".

Source: Own study based on research.

Respondents repeatedly emphasized that ESG governance is changing the way market signals are interpreted. Requirements imposed by Carrefour, Castorama, and Rossmann, the EcoCert system, the Green Impact Index, REACH monitoring, and CLP monitoring all support the earlier detection of innovation opportunities. R1 indicates that customer requirements are the first signal to initiate product changes, while ESG leads companies to interpret them more broadly, taking into account environmental impact. R3 indicates that the Green Impact Index has become an internal compass for product development. The assessment is based on an analysis of over 50 criteria covering the entire product life cycle, including: composition and biodegradability of the formula, origin of raw materials, CO_2 emissions, water consumption, packaging (weight, recycled content, recyclability), transport, and production

conditions. This is confirmed by Groupe Altaïr's sustainable development strategy, which stipulates that ESG (Environmental, Social, Governance) principles will be integrated into key management processes and innovation activities. ESG is considered a key factor in determining the development of products, processes, and stakeholder relations. This strategy is based on three fundamental pillars: Planet, Employees, and Consumers. In the Planet area, activities focus on reducing the negative impact of operations on the climate and natural resources, in particular by reducing CO_2 emissions and improving the environmental profile of products. The Employees pillar emphasizes the role of working conditions, skills development, and shaping organizational commitment. In the Consumers area, the importance of product safety, quality, and transparency is emphasized (Groupe Altaïr CSR Report 2024, Groupe Altaïr Manifesto: Corporate Social Responsibility. Our Commitments to Sustainable Development. Internal Company Document, 2024).

In the company's management model, ESG does not function as a separate area of activity, but rather as an element integrated with core organizational processes. In the environmental area, particular importance is assigned to reducing the carbon footprint across the entire value chain (scopes 1, 2, and 3 emissions), in line with international decarbonization guidelines, including the global Science Based Targets Initiative (SBTi). In governance, formalized management mechanisms, including codes of conduct, compliance procedures, and internal control systems, including whistleblowing solutions and anti-corruption policies, play a significant role. In the social area, the role of organizational culture and human capital development is emphasized.

ESG governance does not automatically generate innovation. First, it influences decision-making. R3 describes that every project has an ESG rating and is assessed by an innovation committee. Projects with a weak ESG profile struggle to achieve priority. Respondents repeatedly emphasized that a new product is not solely an R&D project. It becomes a project of the marketing, purchasing, finance, logistics, and compliance departments. Thus, ESG governance is a mechanism for collaboration, both internally and externally. The innovation process includes product lifecycle analysis, the implementation of eco-design principles, and the final evaluation of solutions. The company's innovation activity encompasses both product and process innovations. Key directions of innovation include the development of more environmentally friendly product formulas, the elimination of selected chemicals (e.g., through the use of internal lists of restricted ingredients), increasing the share of recycled materials in packaging, and reducing the use of plastics.

Interviews indicate that ESG governance forces the formalization and reconfiguration of processes. Evidence includes the emergence of electronic document flow, eco-friendly logistics processes, a change in means of transport, and new packaging processes. R1 describes the transition to multimodal transport, a change in logistics provider, and the elimination of plastic fillers. Analysis of organizational documentation confirms this statement. ESG principles have been incorporated into strategic documents and management systems, and responsibility for

their implementation has been decentralized and assigned to various management levels. At the same time, ESG requirements are being extended to business partners, including through codes of commercial relations covering environmental protection, business ethics, and supply chain responsibility. The company's operations emphasize the operationalization of ESG goals through the use of measurable indicators (KPIs) and analytical tools. Solutions that enable the assessment of the environmental impact of products throughout their life cycle, such as the Green Impact Index, are particularly important. These tools support decision-making processes and enable the incorporation of environmental criteria into product design.

ESG governance is considered a mechanism for ensuring the quality of decisions. Respondents R1, R3, R4 note that although ESG governance may slow down decisions, it also fosters the creation of significant innovations.

5. Synthetic Conclusions

The relationships revealed in the axial coding revealed three mediating mechanisms (Table 4). ESG governance, in particular its elements: ESG strategy, KPIs for monitoring the achievement of ESG goals, SBTi objectives, stakeholder management, and sustainable reporting, positively impact sensing. They enhance the organization's ability to detect changes in regulations, technology, and stakeholder expectations. Based on the identified signals, investment decisions are made, projects are prioritized, and resources are allocated (M1: Sensing → Seizing). These decisions lead to the reconfiguration of processes (e.g., multimodal transport, supplier switching, document digitization, dosing optimization), technologies (e.g., reformulation, elimination of toxic substances, increasing the share of recycled material, life cycle assessment), relationships with partners (e.g., co-creation, co-branding, supplier selection, collaboration with laboratories), and organizational structures (M2: Seizing → Reconfiguring). Reconfiguration enables the development of new products, processes, technologies and organizational solutions (M3: Reconfiguring → Innovation).

Table 4.
Mediation mechanisms

Mediation	Relation	Mechanism
	ESG Governance → Sensing	ESG enhances an organization's ability to detect changes in regulations, technology, and stakeholder expectations.
M1	Sensing → Seizing	Identified signals serve as the basis for investment decisions, project prioritization, and resource mobilization.
M2	Seizing → Reconfiguring	These decisions lead to the reconfiguration of processes, organizational structures, technologies, and relationships with partners.
M3	Reconfiguring → Innovation	Reconfiguration enables the development of new products, processes, technologies, and organizational solutions.

Source: Own study based on research.

Based on the identified mediation mechanisms, an integrated theoretical model was constructed (Figure 2). It presents a mediation mechanism in which ESG governance influences innovation through three dynamic capability processes: sensing, seizing, and reconfiguring.

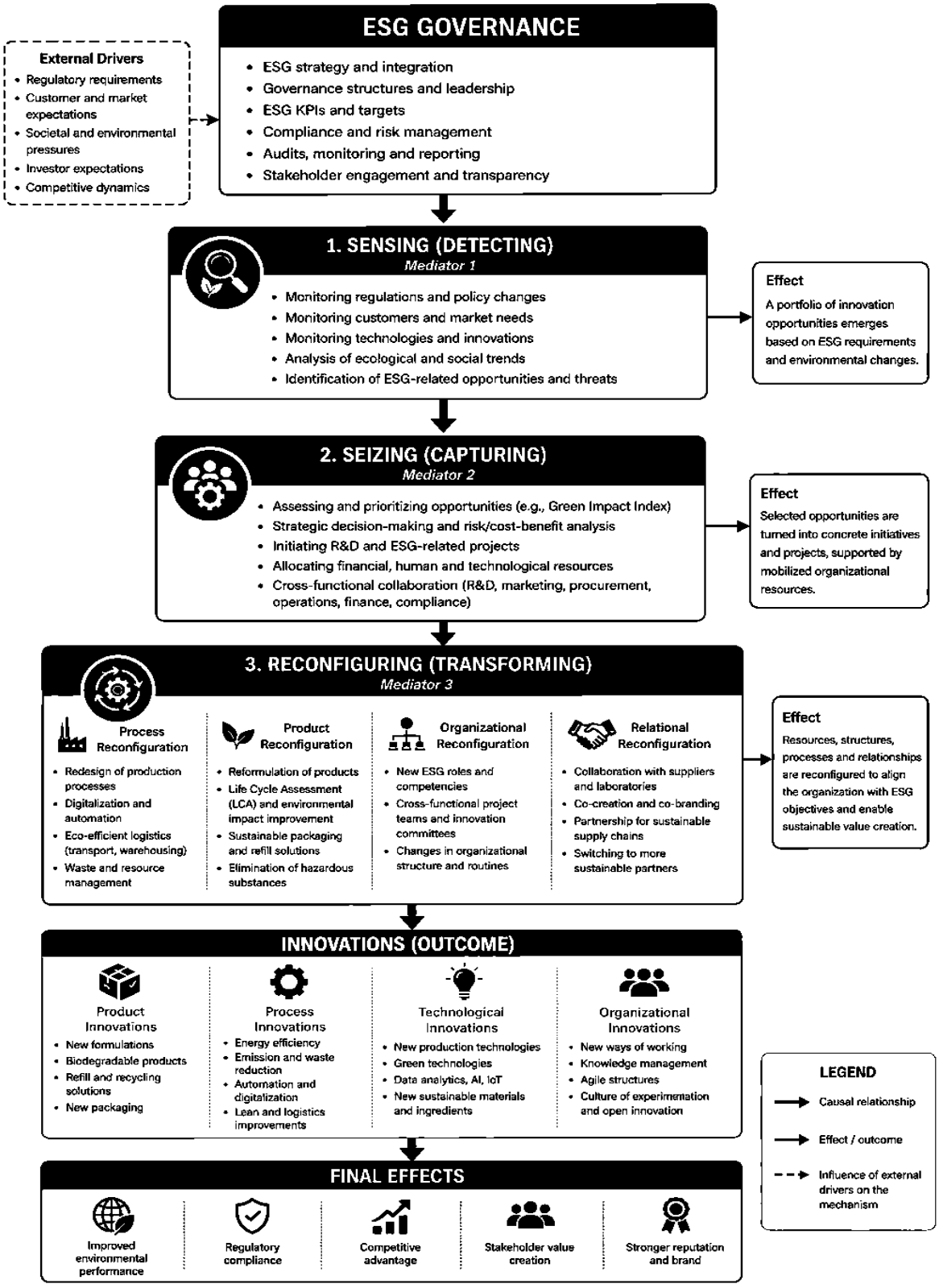


Figure 2. Integrated theoretical model.

Source: Own study based on research.

In summary, ESG governance does not directly influence innovation, but rather acts as a system of rules, filters, and criteria that triggers a chain of dynamic processes: sensing → seizing → reconfiguring. Only the reconfiguration process—including product redesign, process reengineering, formalization of new ESG structures, transformation of supplier relationships, and implementation of sustainable technologies—materializes previously identified opportunities in the form of innovation. This means that reconfiguring acts as a direct mediator between resource mobilization (seizing) and innovation outcomes, completing the mechanism consistent with the classic approach to dynamic capabilities.

The development of dynamic capabilities results in sustainable innovations that are compliant with regulations, market-reliable, and strongly aligned with customer expectations. Finally, it is worth mentioning that the sensing, seizing, and reconfiguring processes occur in parallel and iteratively. The boundaries between them are fluid, allowing the organization to simultaneously identify new opportunities, make decisions about their utilization, and reconfigure its resources and processes.

Research findings indicate that ESG management can have negative consequences for a company's decision-making and innovation processes. One of the most significant limitations is the increased time taken to make decisions. This stems from the need to consider a broader set of criteria, such as environmental compliance, social impact, stakeholder expectations, reputational risk, and corporate governance requirements. Decisions that were previously based primarily on economic and technological criteria now require additional analysis, consultation, and approvals.

A second negative consequence is increased organizational costs. Implementing ESG requires developing systems for monitoring, reporting, auditing, and documenting company operations. This includes the costs of hiring specialists, using external consulting services, implementing measurement tools, and adapting processes to regulatory requirements. As a result, some financial and human resources that could be directly allocated to research and development are instead allocated to implementing ESG requirements.

Another significant problem can be the increase in bureaucracy. Extensive compliance procedures, reporting obligations, and multi-step approval processes can limit an organization's flexibility. In practice, this means that innovative projects must undergo a greater number of formal assessments, committees, and oversight processes. This can slow down the pace of experimentation, hinder the rapid testing of new solutions, and weaken the organization's ability to respond to market changes.

ESG management can also exacerbate risk aversion. Fearing negative stakeholder assessments, regulatory risk, or accusations of greenwashing, companies may avoid projects that are more radical, uncertain, or difficult to clearly assess in terms of their environmental and social impact.

The negative impact of ESG can also be seen in the number of innovations implemented. If every project must meet numerous environmental, social, and governance criteria, some potential initiatives may be rejected at an early stage. This is particularly true for projects that are technologically or commercially promising but do not align with ESG criteria. As a result, a company may limit its innovation portfolio, reducing the diversity of experiments and potential development directions.

6. Conclusion

The conducted research enabled us to solve the research problem and achieve the established research goals. We identified the impact of ESG governance on dynamic capabilities in a company operating in the household chemicals industry, and we identified the mechanisms of connections between ESG governance, dynamic capabilities (sensing, seizing, and reconfiguring), and innovation. Due to the qualitative nature of the research, conducted through a single case study, there is no basis for generalizing the findings to the entire industry.

Further research is needed to deepen our understanding of the mechanisms linking ESG governance, dynamic capabilities, and corporate innovation. Initially, it is advisable to conduct quantitative research on a larger sample of companies representing various economic sectors. The use of structural equation modeling (SEM) would enable us to verify the proposed theoretical model and assess the strength and direction of the relationship between ESG governance, dynamic capabilities, and innovation outcomes. Confirming the mediating role of the capabilities of sensing, seizing, and reconfiguring resources would be particularly important.

Another avenue of research should be longitudinal studies, allowing for the observation of changes occurring in companies over several years. This approach would enable us to analyze the sequential nature of the processes in which implementing ESG governance principles leads to the development of dynamic capabilities, and subsequently to the emergence of product, process, organizational, and marketing innovations. Such studies could also identify time lags between the implementation of specific ESG practices and the achievement of innovation outcomes.

It is also worthwhile to expand the scope of research to include analysis of contextual moderators. Factors such as company size, ESG maturity level, R&D intensity, an organizational culture that supports innovation, top management commitment, the level of company digitalization, as well as regulatory pressure and stakeholder expectations may be of particular interest. These factors can either strengthen or weaken the impact of ESG governance on the development of dynamic capabilities and innovation outcomes.

Another important area for further research is the analysis of feedback loops. Future research could verify whether achieved innovations contribute to the further development of ESG practices and the strengthening of an organization's dynamic capabilities. This would allow for a better understanding of the bidirectional nature of the relationship between ESG and innovation.

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INFLATION EXPECTATIONS ACCURACY AND ERRORS TRANSMISSION AMONG THE AGE GROUPS IN POLAND

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Purpose: The study aims to examine the age-related heterogeneity of inflation expectations errors formed by Polish consumers. First, the analysis was intended to verify whether consumers who experienced hyperinflation in their most productive ages are more prone to overstate the future inflation in comparison to other age groups, accounting for different levels of inflationary pressures. Second, we examine the extent to which the potential bias is transmitted into the younger age groups.
Design/methodology/approach: The analysis has been performed on the survey-based one-year-ahead monthly consumer inflation expectations of four age groups in Poland, quantified with the Carlson-Parkin method (1975) adjusted by Batchelor and Orr (1988). The methodology covers the forecast errors analysis, Peseran-Timmerman test, Diebold-Mariano and HLN tests for significant difference in accuracy, regression analysis, and Granger causality test.
Findings: When the inflation expectations are formed under the inflation target range environment, the accuracy of inflation expectations of consumers within age groups does not differ significantly. Under the high inflation environment, the accuracy of inflation expectations of consumers who experienced hyperinflation in their productive ages differs significantly from the youngest age group of consumers who do not have such experience. This difference increases when the inflation (at the time when the expectations are formed) also increases. Under the high inflation environment in Poland, the oldest age group of consumers is not effective in learning from their mistakes. The oldest group errors are transmitted to the two younger groups and enhance their inflation expectations errors. However, we cannot confirm that the youngest (fourth) group of consumers is affected by the oldest group errors, which may indicate the lack of inflation expectations accuracy transmission.
Research limitations/implications: The research can be expanded by expectations error analysis in other hyperinflation-experienced countries.
Practical implications: Inflation expectations heterogeneity may disrupt implementing common monetary policy and the process of uniform inflation expectations management by central banks.
Originality/value: In the case of Poland, the experience of hyperinflation and corresponding memory-based response can be considered as a valid determinant of the expectations heterogeneity.
Keywords: inflation expectations, accuracy, monetary policy.
Category of the paper: Research paper.

1. Introduction

Inflation expectations play an important role in shaping a country's monetary policy and are widely considered one of the determinants of the actual inflation rate (e.g., Madeira, Zafar, 2014; Moessner, 2024; Verbrugge, Zaman, 2021). The problem of examining inflation expectations in shaping current inflation rates gained popularity in the late 1960s. of the 20th century, when the expected inflation rate was incorporated into the expectations-augmented Phillips Curve (EAPC) model, developed by M. Friedman and E. Phelps. In recent years, more and more attention has been devoted to measuring consumers' inflation expectations, which influence their wage demands as well as their current propensity to consume and invest (Vincent-Humphreys et al., 2019). The high heterogeneity of consumer inflation expectations remains a challenge in this regard, making it difficult for monetary authorities to effectively manage them and anchor them at the inflation target level.

The study aims to examine the age-related heterogeneity of inflation expectations formed by Polish consumers in terms of their accuracy, understood as the difference between predicted and observed inflation rates. More specifically, the analysis was intended to verify whether consumers who experienced hyperinflation in their most productive ages are more prone to overstate the future inflation in comparison to other age groups, accounting for different levels of inflationary pressures. Second, we examine the extent to which the potential bias is transmitted into the younger age groups. To do so, we have performed the inflation expectations forecasts analysis, Diebold-Mariano, and HLN tests. The error transmission has been examined with the use of OLS regression models and the Granger causality test based on VAR (1) models. Both goals were achieved with the use of the one-year ahead survey-based inflation expectations (following D'Acunto, Weber, 2024) from four age groups in Poland.

Poland has been implementing an inflation-targeting regime for at least 25 years, with a set inflation target of 2,5% and a 1% range, measured by the CPI index. The country experienced hyperinflation in 1989-1990 during the first phase of its rapid economic transformation. This makes it a prime example of a country where the youngest age group does not have any hyperinflation experiences, and the older group experienced it during their productive ages (20-60 years).

The rest of the article is structured as follows. In the "Literature review" section, we briefly discuss the current state of knowledge related to the most relevant determinants of consumer inflation expectations formation, with the greatest emphasis put on the learning-based mechanisms linked to previous experiences. Then, after a short description of the data sources and general stages of the analytical framework, the section "Results and Discussion" presents the detailed findings for each of the stages, and explains further the analytical methods, assumptions, and the rationale behind them. The study ends with the "Conclusions" section, which provides the answers to the main research questions.

According to our knowledge, the detailed study of age-related heterogeneities of inflation expectations accuracy in the hyper-inflation experienced country has not been done so far. The authors believe that the study based on Polish economic experience can provide valuable insights and facilitate the process of inflation expectations management.

2. Literature review

2.1. The heterogeneity of consumer inflation expectations – the overview

The level and accuracy of inflation expectations vary both between groups of economic agents and within them. The largest forecast error is observed in the case of households, which tend to present a persistent, structural upward bias regardless of the current inflation environment (D'Acunto et al., 2025; Andre, Schaffranka, Weber, 2026). The increased inaccuracy of households' predictions is attributed to two main groups of factors (Angelico, Giacomo, 2019; D'Acunto et al., 2024; Anesti, Esady, Naylor, 2025):

a. Imperfect information – in comparison to other groups of economic agents, they tend to form their judgment based on media coverage and/or personal experiences rather than any form of economic analysis. Moreover, individuals often don't even perceive inflation in terms of aggregate CPI/HICP indices and describe the changes in their personal "inflation rates" – the strain levels related to the purchase of goods they tend to acquire most often.
b. Behavioral factors – expanding on the previous point, individual consumers tend to exercise a selective call approach and put an excessive weight on recent, salient price changes within the sets of goods they purchase frequently. As a result, food prices play a much larger role in aggregate dynamics than other components of the basket, such as energy.

Within the analysed group, the lowest precision of inflation expectations can be observed among households with the lowest level of education and/or income, where the impact of the above factors is the greatest. Lower education levels generally translate into lower financial literacy, and higher income levels may reduce a household's vulnerability to inflation. Beyond the main driver, household socioeconomic status, there is no universal agreement on distinct demographic factors affecting expected inflation levels. Higher expected inflation, along with lower predictive accuracy, has been observed in the case of women, but the effect is usually described as secondary to the differences in education and income levels (Gnan, Langthaler, Valderrama, 2011). Similarly, there are no universal, consistent age-related patterns related solely to the direction of the bias. For example, a survey conducted by D'Acunto et al. (2025) across 31 economies in March and April 2025 showed significantly lower levels of expected

inflation among respondents above the age of 50. But the opposite conclusions can be drawn, for example, from ECB Consumer Expectations Survey results from November 2025 (European Central Bank, 2026), where the younger respondents (aged 18-34) continued to report lower inflation perceptions and expectations than older ones (aged 35-54 and 55-70). More clarity can be derived from another, mechanism-based stream of research that focuses on the generational differences in the consumer inflation expectation formation, presented in the next section of the article.

2.2. Learning-based sources of inflation expectations dispersion

Consumer inflation expectations are heterogeneous due to different learning models and the ability to process the information (Pfajfar, 2013). The set of introduced most common learning models includes: the recursive least squares with infinite memory learning model (Evans, Honkapohja, 2001), the constant gain learning model (Orphanides, Williams, 2005; Milani, 2007), and the learning from experience model introduced by Malmendier and Nagel (2016). The concept of learning from experience described by Malmendier and Nagel (2016) states that consumers form their expectations based on the historical inflation rates with the exponential function of weights. However, these historical inflation rates are strongly connected with the agents' lifetime experiences. This means that the consumers may be divided into cohorts due to their age, and the constant gain may depend on their age. The historical inflation rate affects only these cohorts that have experienced this inflation rate period, and after their disappearance, the impact of these inflation periods emerges. It supports the assumption that the younger agents are more affected by more recent experiences than the older ones.

This is further supported by broader, cross-country research related to the consumer response to the highly volatile economic environment. Following Coibion et.al. (2018), households and firms are remarkably inattentive to inflation dynamics in developed countries that have experienced low inflation rates for several decades, but economic agents in high-inflation environments seem to pay considerable attention to inflation. Ehrmann and Tzamourani (2009) (based on the survey responses) conducted the inflation aversion study, indicating that the memories of high inflation affect agents' preferences about the importance attached to price stability. Similar conclusions can be drawn from studies related to other forms of significant economic stressors. For example, the study performed by Fungacova et.al. (2019) shows that experience with banking crises influences agents' trust in commercial banks to the extent depending on the age at which the crisis was experienced. More precisely, the banking crisis affects trust in banks negatively only if the crisis took place when the individual was between 41 and 60 (Fungacova et. al., 2019). Knight (2012), based on the Greek experiences, analysed how specific historical events (the Great Famine in 1941-43) became embodied during the last economic crisis in 2008. This issue has also been noticed by Pipyrou (2015) based on experiences in Southern Italy.

Both research streams combined support the hypothesis that a country with a history of hyperinflation periods is characterized by a statistically significant difference in the accuracy of the consumer inflation expectations between the age groups (assuming that the experience of hyperinflation cannot be equally attributed to all of them). The effect should be especially visible under a high inflation environment, which triggers the memory-based inflation aversion response. The study aims to verify this hypothesis with an example of Poland, which experienced a periodic hyperinflation in 1989-1990, in the first phase of the country's transformation to a market economy. By doing this, we assume that hyperinflation during the post-communist transformation in Poland can be considered as an economic stressor sufficient to affect the inflation expectations formation mechanism. Additionally, we extend the analysis and verify the existence of transmission of forecast errors between the age groups, which has been previously confirmed in literature by Braggion et al. (2024). To the best of our knowledge, the study on the transmission of inflation forecast errors among the age groups, accounting for both its impact and direction, has not been done so far.

3. Methods

The data on inflation expectations has been collected from the EC Business and Consumer Survey. The monthly aggregate answers have been quantified with the use of Carlson Parkin's method (1975) adjusted to six answers by Batchelor and Orr (1988). We use the CPI inflation rate as a scaling factor. The survey data are gathered and aggregated for four age groups of responders: (1)16-29 (AGE1), (2) 30-49 (AGE2), (3) 50-64 (AGE3), and (4) 65 and older (AGE4). The accuracy of inflation expectations was measured as an absolute difference between the inflation expectations in time t and the realized inflation in time t+12

The general analysis has been performed on monthly data within the time span from May 2001 to December 2024, with the main focus on high inflation periods in Poland. The consumers' inflation expectations have been divided into two subsamples within this time line in regards to inflation environment and the inflation targeting regime. An inflation in the range of <1,5%; 3,5%> is considered a stable inflation environment, as it remains within the acceptable deviations from the inflation target in Poland. The inflation above 3.5% exceeds the inflation target range, and therefore is regarded as a high inflation environment. The first subsample (S1) consists of inflation expectations formed during the inflation target range environment (CPI inflation in a target range <1,5%; 3,5%>), and the second one (S2) consists of inflation expectations formed during the high inflation periods (CPI inflation above 3,5%). To obtain the remaining two samples, we have excluded from the whole sample the expectations that have been formed under the low inflation environment (below 1.5%) and

deflation. The main descriptive statistics for inflation expectations formed under these two inflation environments (subsamples) by four age groups are shown in Table 1.

Table 1.
Descriptive statistics of inflation expectations of consumers in Poland among four age groups in two inflation environments (in the time when expectations were formed): inflation target range(S1), and high inflation environment (S3)

Inflation environment	Expectations	Avg.	Me	S.D.	Min	Max
S1: inflation target range	EXP_AGE1	3,67	3,71	0,41	2,98	4,25
	EXP_AGE2	3,75	3,60	0,45	3,09	4,62
	EXP_AGE3	3,83	3,79	0,43	3,28	4,93
	EXP_AGE4	3,82	3,81	0,40	3,21	4,78
	CPI(t+12)	2,53	2,80	1,48	0,20	4,30
S2: high inflation environment	EXP_AGE1	10,10	9,46	4,44	4,33	17,77
	EXP_AGE2	10,46	9,42	4,71	4,40	18,26
	EXP_AGE3	10,08	9,14	4,61	4,49	17,71
	EXP_AGE4	9,56	8,30	4,35	4,04	16,46
	CPI(t+12)	9,86	10,10	5,75	2,00	18,40

Note. S1/S2- inflation environment. EXP_AGE1/EXP_AGE2/EXP_AGE3/EXP_AGE4 – quantified inflation expectations of consumers in a specific age group.

Source: own calculations.

The study has been divided into three stages, which are presented in Table 2. The first stage has been performed on two subsamples. The next two stages were based on the second subsample- a high inflation environment.

As a first step, we verified the inflation expectations accuracy among the age groups under the inflation target range environment and the high inflation environment. The first step is an introductory one to determine the inflation environment under which the differences in inflation expectations accuracy exist among the age groups. Our pre-assumption stated that the oldest groups of consumers may be more attentive to high inflation due to their experiences of hyperinflation in their most productive ages. Due to this, the accuracy of inflation expectations formed under high inflation expectations by the oldest and younger groups may differ significantly (the oldest group may overestimate the inflation or, on the other hand, form it more accurately). The inflation expectations evaluation has been performed based on the chosen forecast error measures: (1) Mean Error (ME), (2) Mean Absolute Error (MAE), (3) Mean Squared Error (MSE), (4) Root Mean Squared Error (RMSE), and (5) Symmetric Mean Absolute Percentage Error (SMAPE) (Hyndman, 2018). The ME, MAE, MSE, RMSE, and SMAPE forecast errors have been used to compare the forecast accuracy among the age groups and inflation environments. We have calculated the Theil U1 Statistics to evaluate the inflation expectations in different age groups and inflation environments with the naive forecasts (where the future values of inflation equal the previous ones) (Theil, 1958). Next, following by Greer (2003), and Fassas and Stephanou (2016) we have examined whether the formed inflation expectations correctly forecasted the sign of inflation over the whole sample period (McCarthy, Snudden, 2023). We intended to check whether these four groups of consumers are able to predict the direction of future changes in inflation. To verify the forecast's

directional accuracy, comparing the inflation expectations at time *t* and realized inflation in time *t+12*, for all age groups within the time span May 2021-Dec 2024, the Pesaran-Timmerman (P-T) test (Pesaran, Timmermann, 1992) has been performed. By its construction, the test covered the whole sample, including the low inflation and deflation environment.

The simple comparison of previously calculated inflation expectations errors is not enough to prove the difference in accuracy (D'Agostino et al., 2006) between the inflation expectations formed by four age groups in the chosen two subsamples (target range (S1) and high inflation environment (S2)) (Faust, Wright, 2013). We performed the Diebold-Mariano test (D-M) based on the MAE error statistic (Diebold, Mariano, 1995) and the Harvey, Leybourne, and Newbold test (HLN) (Harvey et. al.,1997) to determine whether the accuracy of inflation expectations formed by different age groups in two subsamples differs significantly from each other (Ang et al., 2007).

In the second step, following Andre et.al. (2026), we tested for the phenomenon of upward bias in inflation expectations errors. We have examined the tendency to misjudge the future inflation in different age groups. To verify the existence of systematic bias between the inflation expectations formed by different age groups under the high inflation environment, a set of linear regressions for the difference between the age groups' expectations over a constant has been estimated. Additionally, assuming this overestimation tendency in reaction to high inflation, we have verified the difference in reaction of consumers' inflation expectations in different age groups to the most recent inflation statistics, so-called reaction dispersion. To do so, we have performed the correlation analysis between the differences in inflation expectations among the age groups and the chosen inflation statistics: 12 months standard deviations (Capistrán, Timmermann, 2009), 12 months average inflation, maximum inflation in the last 12 months, and maximum inflation in the last 6 months. By this, we have examined the sensitivity to inflation dispersion, and long- and short-term high inflation in forming the expectations by four different age groups of consumers.

The third stage covers the verification of the transmission of the inflation expectations errors between the age groups during the high inflation periods. To examine whether the inflation expectations errors made by one age group are transmitted and affect the accuracy of the other age groups, we have considered the high inflation period (time span 2021:07-2023:12, N = 30) and estimated the set of four OLS regressions between the accuracy of inflation expectations in four age groups. We have estimated four linear regressions with the independent variables lagged by two months, assuming the two months period of information spread between the age groups. The regressions also covered the lagged by two months dependent variable to capture the process of self-learning on mistakes by each age group. The regression specifications are as follows:

$$accAGE1_t = a + a_1 accAGE1_{t-1} + a_2 accAGE1_{t-2} + a_3 accAGE2_{t-1} + a_4 accAGE2_{t-2} + a_5 accAGE3_{t-1} + a_6 accAGE3_{t-2} + a_7 accAGE4_{t-1} + a_8 accAGE4_{t-2} + e \quad (1)$$

$$accAGE2_t = a + a_1 accAGE1_{t-1} + a_2 accAGE1_{t-2} + a_3 accAGE2_{t-1} + a_4 accAGE2_{t-2} + a_5 accAGE3_{t-1} + a_6 accAGE3_{t-2} + a_7 accAGE4_{t-1} + a_8 accAGE4_{t-2} + e \quad (2)$$

$$accAGE3_t = a + a_1 accAGE1_{t-1} + a_2 accAGE1_{t-2} + a_3 accAGE2_{t-1} + a_4 accAGE2_{t-2} + a_5 accAGE3_{t-1} + a_6 accAGE3_{t-2} + a_7 accAGE4_{t-1} + a_8 accAGE4_{t-2} + e \quad (3)$$

$$accAGE4_t = a + a_1 accAGE1_{t-1} + a_2 accAGE1_{t-2} + a_3 accAGE2_{t-1} + a_4 accAGE2_{t-2} + a_5 accAGE3_{t-1} + a_6 accAGE3_{t-2} + a_7 accAGE4_{t-1} + a_8 accAGE4_{t-2} + e \quad (4)$$

where: *accAGE1/accAGE2/accAGE3/accAGE4* – inflation expectations accuracy in the chosen age group.

To determine whether the inflation expectations accuracy of the oldest group of consumers affects the inflation expectations accuracy of the younger groups, indicating that the older group captures additional predictive information, we tested for Granger causality. To do so, we have performed four Granger causality tests between the accuracy of inflation expectations of the oldest group (AGE4) and the three younger age groups (AGE1, AGE2, AGE3). The Granger causality has been tested based on four VAR (1) models, as follows:

$$accAGE4_t = a_{11} accAGE4_{t-1} + a_{12} accAGEN_{t-1} + e_{1t},$$
$$accAGEN_t = a_{21} accAGE4_{t-1} + a_{22} accAGEN_{t-1} + e_{2t},$$

where:

accAGE4 – inflation expectations accuracy in the oldest age group (AGE4),

accAGEN – inflation expectations accuracy in the younger age groups (N = 1, 2, 3).

The lag length has been selected according to the AIC, BIC, and HQC criteria.

Table 2.
Stages of the research

Stage	Aim	Methodology	Sample
1.	Inflation expectations accuracy	Mean Error (ME), Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), Symmetric Mean Absolute Percentage Error (SMAPE)	S1, S2
	Comparison of inflation expectations with the naive forecasts	Theil's U1 statistics	S1, S2
	Inflation expectations directional accuracy	Pesaran-Timmerman (P-T) test	S
	Significance of the differences in inflation expectations accuracy	Diebold-Mariano test (D-M), Harvey, Leybourne, and Newbold test (HLN)	S1, S2
2.	Inflation expectations systematic bias	A set of linear regressions estimated over a constant for the difference between the age groups	S2
	Reaction of consumers' inflation forecasts from different age groups to the most recent inflation measures	Pearson correlation: the differences in inflation expectations among the age groups and 12 months inflation standard deviations, 12 months average inflation, maximum inflation in the last 12 months, and maximum inflation in the last 6 months.	S2

Cont. table 2.

3.	Inflation forecasts errors transmission among the age groups and self-learning within the groups	Lagged linear regressions for the accuracy of inflation expectations of four age groups.	S2
		Granger causality tests based on VAR (1) models	S2

Note. S1/S2- inflation environment.

Source: own.

4. Results and Discussion

4.1. Inflation expectations accuracy among different groups of consumers

The Theil's U1 statistics were similar across all groups, indicating that consumers in all age groups outperform naive forecasts (U1<1). The inflation expectations accuracy results are shown in Table 3. The results of the Peseran-Timmerman test indicate that inflation expectations of all age groups accurately forecast the direction of the change in future inflation (Table 4). The inflation expectations errors are larger under a high inflation environment than under an inflation target range environment. Under the high inflation environment, the inflation expectations errors seem to be larger in the oldest age group (AGE4) than in the youngest age group (AGE1), and this effect is not so noticeable under the target range environment (Table 3). The results of the D-M test and HLN test indicate that there is no significant difference between the accuracy of expectation between all age groups in the time span May 2001- Dec. 2013, but there is a significant difference in accuracy between the youngest (AGE1) and the oldest (AGE 4) age groups of consumers under the high inflation environment (Table 5). As a conclusion of this stage, to cover the errors transmission among the age groups, we focus, in the next steps, on the second expectations subsample- expectations formed under a high inflation environment.

Table 3.
Inflation expectations errors made by different age groups in Poland

	CPI, May 2001-Dec.2024, n=272				**CPI <1,5%; 3,5%>, S1**				**CPI>3,5%, S2**			
Errors	AGE1	AGE2	AGE 3	AGE 4	AGE1	AGE2	AGE3	AGE4	AGE1	AGE2	AGE3	AGE4
ME	0.17	0.22	0.14	0.10	1.01	0.98	0.96	0.98	-1,02	-1.22	-1.11	-1.22
MSE	11.12	10.03	10.41	11.17	4.69	4.72	4.72	4.71	25.45	25.57	23.29	25.57
RMSE	3.34	3.17	3.23	3.34	2.17	2.17	2.17	2.17	5.04	5.06	4.83	5.06
MAE	2.22	2.13	2.16	2.20	1.62	1.61	1.62	1.62	3.61	3.58	3.43	3.58
SMAPE	0.82	0.80	0.81	0.82	0.58	0.57	0.57	0.58	0.66	0.65	0.64	0.65
U1 Theil	0.36	0.34	0.34	0.35	0.36	0.36	0.35	0.36	0.35	0.34	0.33	0.34

Note: The data analysis for this paper was generated using the Real Statistics Resource Pack software (Release 8.9.1). Copyright (2013 – 2023) Charles Zaiontz. www.real-statistics.com.

Source: own calculations.

Table 4.
Peseran-Timmerman test results within the age groups, May 2021-Dec.2024

Expectations	AGE 1		AGE 2		AGE 3		AGE 4	
Test	Test Statistics	P value	Test Statistics	P value	Test Statistics	P value	Test Statistics	P value
CPI (t+12)	4.28*	p<0.001	6.34*	p<0.001	7.74*	p<0.001	6.53*	p<0.001

Note: n = 272. *The null hypothesis states that the inflation expectations do not forecast the direction of the change in future inflation (t+12). In each of the age groups, the null hypothesis has been rejected under .1 significance level. The data analysis for this paper was generated using the Real Statistics Resource Pack software (Release 8.9.1). Copyright (2013-2023) Charles Zaiontz. www.real-statistics.com.

Source: own calculations.

Table 5.
D-M and HLN test results within the age groups

	D-M Test				HLN Test				
All sample	**Expectations**				**All sample**	**Expectations**			
		AGE 2	AGE 3	AGE 4			AGE 2	AGE 3	AGE 4
Expectations	AGE 1	-0.09 (0.92)	1.43 (0.19)	1.47 (0.14)	Expectations	AGE 1	-0.1 (0.92)	1.41 (0.16)	0,12 (1.57)
	AGE 2		1.15 (0.25)	1.06 (0.29)		AGE 2		1.23 (0.22)	1.14 (0.25)
	AGE 3			0.8 (0.42)		AGE 3			0.86 (0.39)
CPI <1.5%; 3,5%>, S1	**Expectations**				**CPI <1.5%; 3,5%>, S1**	**Expectations**			
		AGE 2	AGE 3	AGE 4			AGE 2	AGE 3	AGE 4
Expectations	AGE 1	0.47 (0.64)	-0.28 (0.78)	-0.15 (0.88)	Expectations	AGE 1	0.52 (0.61)	-0.3 (0.76)	-0.16 (0.87)
	AGE 2		0.16 (0.87)	0.46 (0.65)		AGE 2		0.17 (0.86)	0.5 (0.62)
	AGE 3			0.35 (0.72)		AGE 3			0.39 (0.70)
CPI>3,5%, S2	**Expectations**				**CPI>3,5%, S2**	**Expectations**			
		AGE 2	AGE 3	AGE 4			AGE 2	AGE 3	AGE 4
Expectations	AGE 1	-0.09 (0.93)	1.54 (0.12)	**-1.67 (0.09)**	Expectations	AGE 1	-0.09 (0.93)	**1.69 (0.09)**	**-1.83 (0.07)**
	AGE 2		1.35 (0.17)	1.21 (0.23)		AGE 2		1.49 (0.14)	1.33 (0.19)
	AGE 3			0.8 (0.42)		AGE 3			0.88 (0.38)

* The null hypothesis states that there is no significant difference in accuracy between two forecasts. Under the high inflation environment, among the youngest group of consumers (AGE 1) and the oldest group of consumers (AGE 4). The null hypothesis has been rejected under .1 significance level. P-values in parentheses. The data analysis for this paper was generated using the Real Statistics Resource Pack software (Release 8.9.1). Copyright (2013-2023) Charles Zaiontz. www.real-statistics.com.

Source: own calculations.

4.2. Inflation expectations systematic bias among the age groups

To examine whether there is a systematic bias between the differences in inflation expectations among different age groups under the high inflation environment, we estimate a set of regressions for the difference between the age groups' expectations on a constant (Table 6). This systematic bias is significant for the differences among the oldest group and the

other groups, indicating the disagreement on inflation expectations among the oldest (AGE4) and the youngest (AGE1) groups.

The correlation analysis results (Table 7) indicate a significant positive correlation between the differences in inflation expectations for almost all age groups (despite the differences between the youngest groups (AGE 1 and AGE 2)) and moving 12 months standard deviations, 12 months average inflation, maximum inflation in 12 months, and maximum inflation in the last 6 months (Table 7). This indicates that the higher inflation environment (larger inflation averages and maximum) and the more unstable inflation environment (larger standard deviation) generate larger differences among the age groups (excl. AGE 1 and AGE 2).

Table 6.
Systematic bias in inflation expectations among different age groups under the high inflation environment - regression over constant results

Variable	**Constant**
expAGE1-expAGE2	-0.16*[0.006]
expAGE1-expAGE3	-0.07[0.07]
expAGE1-expAGE4	0.13*[0.08]
expAGE2- expAGE3	0.09[0.06]
expAGE2-expAGE4	0.029*[0.08]
expAGE3-expAGE4	0.2*[0.006]

Note: Standard errors in parentheses. * Significant under .1.

Source: Own calculations.

Table 7.
Correlation coefficients between the differences in inflation expectations formed by different age groups and the chosen inflation statistics

CPI>3,5%	**expAGE1-expAGE2**	**expAGE1-expAGE3**	**expAGE1-expAGE4**	**expAGE2-expAGE3**	**expAGE2-expAGE4**	**expAGE3-expAGE4**
Inflation moving standard deviation 12M	-0.17	0.14	0.33***	0,35***	0.47***	0.3***
Inflation moving average 12M	-0.04	0.47***	0.6***	0.61***	0.66***	0.29**
Inflation moving MAX12M	-0.09	0.38***	0.55***	0.56***	0.63***	0.33**
Inflation moving 6M	-0.19*	0.31***	0.55***	0.58***	0.72***	0.42***

Note: * Significant under .1, ** .05, *** .001

Source: Own calculations.

According to the analysis above, we found that a high inflation environment in Poland generated significant differences in accuracy among the expectations formed by the youngest age group (AGE 1) and the oldest age group (AGE 4). This result is also visible in Figure 1 – under the high inflation environment, the differences between inflation expectations of the oldest group of consumers (AGE4) and the youngest (AGE 1) drastically increase.

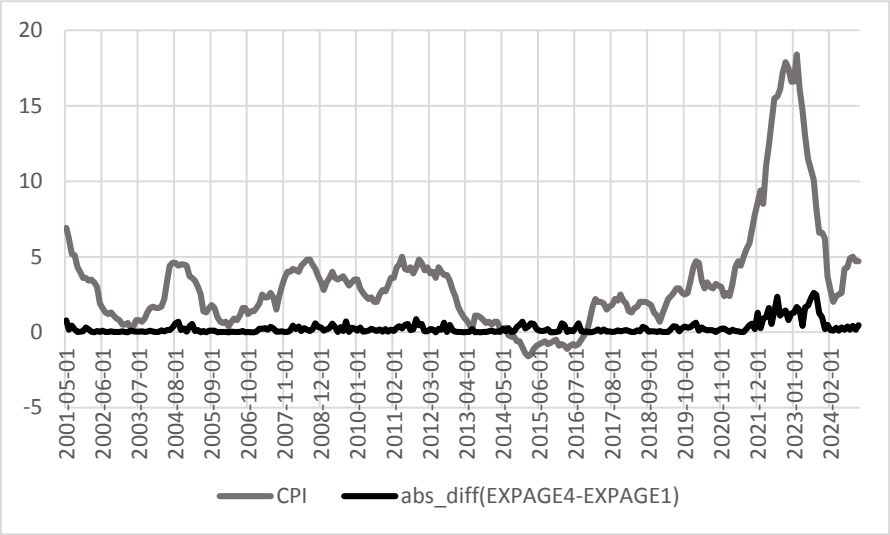

Figure 1. Comparison of the inflation and the difference between inflation expectations of the oldest (AGE4) and youngest (AGE1) groups of consumers.

Source: own.

4.3. Inflation expectations errors transmission among the age groups

To examine whether the inflation expectations errors made by the oldest age group (AGE 4) are transmitted and affect the accuracy of the youngest age groups, we investigated the high inflation period (time span 2021:07-2023:12, N = 30) and estimated the set of OLS regressions, and further performed the Granger causality tests based on VAR (1) models. The inflation expectations accuracy is measured as the difference between the inflation expectation formed at time t and the realized inflation at time t+12. The larger the values of the accuracy, the larger the errors made.

The results of OLS regressions are shown in Table 8 and highlight two main points. First, the consumers from age groups 1, 2, and 3 are learning from their mistakes. This learning effect is not significant for the oldest age group (AGE 4). Second, the lagged errors of inflation expectations in the oldest age group (AGE 4) affect the accuracy of each younger group and increase their forecast errors. The errors made by the oldest group seem to be transmitted to the younger age groups, which in turn contribute to their own mistakes.

Table 7.
Transmission of inflation expectations errors among the different age groups - OLS regression results

	Accuracy of inflation expectations within groups								
Variable	**AGE1 (t-1)**	**AGE1 (t-2)**	**AGE2 (t-1)**	**AGE2 (t-2)**	**AGE3 (t-1)**	**AGE3 (t-2)**	**AGE4 (t-1)**	**AGE4 (t-2)**	**Rsq.**
accAGE1		-0.74* [0.37]	-0.74* [0.37]				0.73* [0.4]	1.18** [0.47]	0.23
accAGE2			-0.43* [0.3]				0.71** [0.34]		0.14
accAGE3					-0.53* [0.32]		0.69* [0.38]		0.1

Cont. table 7.

accAGE4		-0.3 [0.3]						0.58* [0.33]	0.12

Note: Standard errors in parentheses. * Significant under 0.1, **significant under 0.05, ***significant under 0.001. White Test, Chi-square test, and LM test results are available upon request.

Source: Own calculations.

As the last stage, we tested for Granger causality based on VAR (1) models between inflation expectations accuracy of the oldest age group and the younger groups. We assume that if the accuracy of the oldest age group (AGE4) Granger-causes the accuracy of inflation expectations of the chosen younger age group, the expectations errors are transmitted from the oldest consumers to the younger ones. The Granger causality tests based on the VAR (1) models for the accuracy of each age group were performed under the null hypothesis that the accuracy of the oldest age group does not Granger-cause the accuracy of the younger age groups under the high inflation environment in Poland. The Granger causality test results under a high inflation environment in Poland (Table 9) confirmed that the errors made by the oldest age group (AGE4) do Granger-cause errors made by younger groups – AGE2 and AGE3. This causality did not exist in the opposite direction- lack of inverse causality. It needs to be highlighted that the expectations errors made by the oldest age group (AGE4) do not Granger-cause expectations errors made by the youngest group – AGE1. It may be treated as an explanation why the accuracy of expectations formed by the youngest and oldest groups of consumers under the high inflation environment differs significantly from each other. In other words, we may state that under the high inflation environment in Poland, past forecast errors made by the oldest age group (AGE4) contain some additional information and are transmitted to the younger age groups (AGE2 and AGE3). However, this transmission does not cover the learning from the oldest group's mistakes, but increases the younger group's errors.

Table 8.

Granger causality test results among the oldest age group (AGE 4) and the younger groups (AGE1, AGE2, and AGE3) under the high inflation environment in Poland, time span 2021:07-2023:12 (N = 30)

Granger causality	**Var model**	**Test value****
accAGE4→accAGE1	Var (1)*	1,0510 [0,3141]
accAGE1→accAGE4		0,067563 [0,7968]
accAGE4→accAGE2	Var (1)*	4,2607 [0,0484]
accAGE2→accAGE4		0,86239 [0,3610]
accAGE4→accAGE3	Var (1)	3,2054 [0,0842]
accAGE3→accAGE4		0,30527 [0,5850]

Notes: * lag length selected according to the AIC, BIC, and HQC criteria. ADF and KPSS tests, Rao F test, LM test, and Doornik-Hansen test results, and detailed VAR (1) models results are available upon request. The accuracy of inflation expectations was represented as a linear combination of the lagged accuracy of the oldest age group (AGE4) and the accuracy of the chosen younger group (AGE1, AGE2, or AGE3). ** For accAGE4→ accAGE2/ accAGE3, the hypothesis assuming the lack of Granger causality is rejected at the .1 significance level.

Source: Own calculations.

4.4. Discussion

The study is based on aggregated survey data, which precludes verification of the impact of individual consumer characteristics on the accuracy of inflation expectations within a single age group. This states a serious limitation of the research. According to the experience-based learning model formulated using US microdata by Malmendier and Nagel (2016), even within the same age cohort, individuals may use different memory-based weights when forming inflation expectations. The weighting scheme of the age-related transmission of errors connected with hyper-inflation experience may differ within the same age group. Additionally, inflation expectations formation, even within the same age group, can also vary due to differences in demographic and socioeconomic characteristics, personal economic experiences, cognitive abilities (D'Acunto et al., 2022), information exposure (Coibion et al., 2022), perceived inflation and reactivity to monetary shocks (Doh et al., 2025), or a high-low inflation environment dependence on expectations formation (Gwak, 2022). Blanchflower, MacCoille (2009) have already proven that inflation expectations dispersion remains even after conditioning on age, and the best way to model it is to include age and socioeconomic interactions. However, these interactions can only be captured in the micro-level analysis.

There are a lot of studies on cross-country heterogeneities in inflation expectations in the euro area, capturing the socioeconomic characteristics (D'Acunto et al., 2024b), forecasting errors (Chen et al., 2022; Brandão-Marques et al., 2023), reaction to economic shocks (Chang et al., 2022), and a general experience-based model (Malmendier, Nagel, 2016). The inflation expectations learning patterns and models have already been verified by Strobach and van der Cruijsen (2015) for Germany, Italy, the Netherlands, France, Belgium, and Spain, but did not directly cover the experience-based learning models. Malmendier et al. (2021) verified the existence of a collective memory component in central banking practice (policy makers). Ehrmann and Tzamourani (2012) proved the existence of the euro area cross-country heterogeneities related to the memories of high inflation. The existence of a collective memory of high inflation and its intergenerational transmission has been analysed by Braggion et al. (2024) and Haffert et al (2021) for Germany.

Despite the broad literature on inflation expectations formation in Poland, there is no research on the impact of hyperinflation experiences on inflation expectations formation and its transgenerational transmission. Economic agents in Poland are attached to price stability due to the implementation of the inflation targeting regime and the hyperinflation experiences during the economic transformation. This distinguishes them from consumers with no such experience. Our study showed that there are significant differences in the accuracy of inflation expectations in Poland made by the oldest group of consumers, who experienced hyperinflation, and the youngest, who did not. These differences between expectations are highly positively correlated with the high inflation environment. The main novelty of the research lies in investigating the transmission of inflation expectations errors between the oldest age group (experienced by hyperinflation) and younger groups. The study proved that only under a high inflation environment, the inflation expectations errors of the oldest age group (AGE4) affect

the two younger groups (AGE2 and AGE3). The Granger causality results showed that the oldest group errors do Granger cause the errors of the two younger age groups- indicating the error transmission from the oldest to the younger and the existence of transgenerational inflation memories, but only under a high inflation environment. This may result in insignificant differences in expectations between age groups (AGE2, AGE3) and (AGE4). However, the inflation expectations from the oldest group (AGE4) do not Granger-cause the inflation expectations of the youngest group (AGE1), indicating that these intergenerational memories may disappear stepwise with time and next generations.

The study is based on the Polish economy, which precludes expanding the results to other countries. The further research includes investigating the countries with similar characteristics to Poland – implementing an inflation targeting regime and previously experiencing hyperinflation, e.g. Czech Republic. This may provide more general results and additionally verify the conclusions drawn from the Polish study.

5. Conclusion

Our results confirm the existence of a statistically significant heterogeneity in relation to consumer inflation expectations accuracy between the two specified age groups – the oldest and the youngest – characterized by vastly diverse past inflation experiences. Moreover, the effect in question systematically increases with the increase in inflation at the time when the expectations are formed. Importantly, this only holds under a high inflation environment, and within the inflation target range, the accuracy of inflation expectations formed by different age groups does not differ significantly from each other. Based on the previous findings in the field and related, we assume that the bias can be attributed to the experiences of hyperinflation during the political transformation of the oldest age group.

Furthermore, we also positively verified that the inflation forecast errors made by consumers from the oldest age group (AGE4) and formed under a high inflation environment are transmitted to younger age groups. What's important, the Granger causality tests allowed us to confirm the directionally one-sided transmission in relation to two middle groups (AGE2, AGE3), but not the youngest (AGE1). The finding supports the assumption that the younger agents are more affected by more recent experiences and might form their inflationary experiences more independently. Also, contrary to the three other age groups (AGE1, AGE2, AGE3), the oldest age group (AGE4) does not seem to be effective in learning from their mistakes, which might add to the continuity of the error transmission mechanism.

Our results contribute to the conclusion that the generally ambiguous role of age in inflation expectations formation does not hold in the case of economies affected by past hyperinflation history. In the case of Poland, the experience of hyperinflation and corresponding memory-based response can be considered as a valid determinant of the consumer heterogeneity in that

regard. This, in turn, may disrupt implementing common monetary policy, the process of uniform inflation expectations management, the effectiveness of central banks' communication tools and messages, as well as the general trust of the public in central banks.

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PRIVATE BANKING AS A RELATIONSHIP-BASED SERVICE: DETERMINANTS OF CUSTOMER SERVICE QUALITY BASED ON EMPIRICAL RESEARCH

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Purpose: This paper identifies the determinants of customer service quality in private banking in Polish banks between 2023 and 2025, focusing on the first contact of a potential client with the bank.
Design/methodology/approach: The study is based on repeated mystery shopping research conducted as part of the "Institution of the Year" project. In each annual edition, 10 banks were assessed by 10 customers, resulting in 100 assessments per year and 300 assessments over the whole period. The scenario covered asset allocation, day-to-day banking, foreign exchange services and, in 2024-2025, investment-related conversations requiring explanations of MiFID II requirements.
Findings: The results show that private banking service quality is primarily relationship-advisory in nature. The adviser remains the central carrier of perceived quality, while digital tools support the advisory relationship but do not replace it. MiFID II requirements can strengthen perceived professionalism when explained as client protection, but can weaken the experience when presented as a formal barrier.
Research limitations/implications: The study concerns the Polish market and the entry stage of the private banking relationship. It does not measure the entire life cycle of cooperation with a private banker.
Practical implications: Banks should strengthen appointment organisation, adviser preparation, needs identification, explanation of regulatory requirements, digital support and post-meeting follow-up.
Originality/value: The paper shifts the analysis of private banking service quality from ranking-oriented comparison to a mechanism-oriented interpretation of customer experience. It proposes a technology-supported relationship-advisory model showing that perceived quality is sequential and cumulative: it is shaped before, during and after the advisory meeting.
Keywords: private banking, banking, service quality, wealth management, MiFID II.
Category of the paper: Research paper.

1. Introduction

Private banking is a specialised area of financial services in which service quality cannot be reduced to the correct execution of instructions, product availability or transactional efficiency. In this segment, clients expect not only banking services, but also care, expertise, personalisation, discretion and time savings. Service quality in private banking should therefore be analysed as a complex construct comprising both the technical and functional dimensions of the service. In the classical approach to service quality, it is important not only what the customer receives, but also how the service is delivered and how the customer interprets the entire interaction process with the financial institution (Grönroos, 1984).

The literature on banking service quality emphasises categories such as reliability, responsiveness, assurance, empathy and the tangible elements of the service environment (Parasuraman et al., 1988). In private banking, however, these categories require further interpretation. A private banking client evaluates not only whether the bank offers specific products, but also whether the adviser can explain them in relation to the client's financial situation, expectations, risk profile and preferred form of engagement. For this reason, service quality in private banking may be understood as the bank's ability to create a relational experience in which the client is convinced that they are dealing with an expert.

Modern private banking operates in an environment of increasing digitalisation of financial services. This does not, however, imply that the adviser's role is disappearing (Capgemini Research Institute, 2026). Recent research on the digitalisation of financial advice, robo-advisory and the automation of professional financial services indicates that competitive advantage in wealth management increasingly depends on the ability to combine personal advice, personalisation, technology and effective customer experience management (Barile et al., 2024; Namyslo et al., 2025; Altrock et al., 2025). Technology does not replace relationships; rather, it provides infrastructure that enables advisory services to be more efficient, personalised and less burdensome for the client. The future, therefore, lies in hybrid models in which the human adviser and the client relationship remain central. At the same time, robo-advisory plays a supporting role in collecting and analysing data and preparing proposals that the human adviser subsequently presents.

This article aims to identify the determinants of service quality in private banking based on original research conducted between 2023 and 2025 (Institution of the Year, 2023-2025). The article addresses the following research question: which elements of the initial contact with the bank determine the perceived quality of service for a potential private banking client? This question is examined in four specific dimensions: first, the role played by the adviser in building trust and a sense of expertise; second, the influence of the service process on the client experience; third, the extent to which the regulatory framework governing investment consultations, in particular the requirements of MiFID II (Directive 2014/65/EU of the

European Parliament and of the Council, 2014), may strengthen or weaken the perceived quality of the relationship; and fourth, changes between 2023 and 2025 in the organisation of the initial contact, the continuation of the relationship and post-meeting communication as elements of the private banking customer experience.

The article combines an empirical analysis of mystery-shopping results with a conceptual framework for the mechanisms that shape service quality in private banking. Quantitative data from the authors' original research provide the basis for identifying these service quality mechanisms.

2. Service quality in private banking in the light of the literature

According to Grönroos, perceived quality arises from the combination of technical quality, that is, what the customer receives, and functional quality, that is, the manner in which the service is delivered (Grönroos, 1984). In private banking, this distinction is particularly important. Technical quality may include the range of investment offerings, deposit products, credit cards, access to investment advice, foreign exchange services, and the ability to contact specialist teams. Functional quality, in turn, is reflected in how the adviser conducts the conversation, whether they can identify the client's needs, whether they communicate in clear language, whether they create a sense of security, and whether they organise the next stages of the relationship properly.

In private banking, these dimensions assume a specific form. Reliability refers not only to the accuracy of information, but also to the adviser's ability to present a consistent, logical and comprehensive account of the bank's capabilities. Responsiveness means not only speed of response, but also the efficiency with which meetings are organised and follow-up contact is maintained. Assurance includes not only the adviser's professional appearance but, above all, the client's conviction that the adviser has the necessary investment, product, and interpersonal competencies. Empathy, in turn, refers to the ability to adapt the bank's offering to the client's specific situation rather than mechanically presenting a catalogue of products.

Research on private banking confirms that service quality in this segment should be analysed differently from service quality in mass retail banking. Lassar, Manolis and Winsor indicated that comparing the SERVQUAL model with the technical-functional approach to service quality provides a better understanding of the various sources of customer satisfaction in private banking (Lassar et al., 2000). Seiler and Rudolf, in turn, showed that customer satisfaction in private banking is largely determined by the value of the service and by the role of the private banker, that is, the person responsible for the customer relationship (Seiler, Rudolf, 2014). These findings are relevant to the present article because they shift the analytical focus from the bank's offering itself to the way in which the offering is explained, personalised

and embedded in the relationship. More recent approaches to private banking and wealth management indicate that the relationship with a high-net-worth client is based on trust, continuity of contact, personalised advice and adviser support, while also being subject to cost, pricing and competitive pressures. Service quality in private banking should therefore be analysed not only as a standard of contact, but also as a condition for the sustainability of the relationship model (Dzhaparov, 2024). In the relationship literature, particular importance is attached to relationship quality, including trust, satisfaction and commitment. Hennig-Thurau, Gwinner and Gremler demonstrated that relational benefits, including security benefits, social benefits and a sense of special treatment, influence relational outcomes such as loyalty and positive word-of-mouth (Hennig-Thurau et al., 2002). Morgan and Hunt, in turn, argued that trust and commitment constitute the basis of long-term marketing relationships (Morgan, Hunt, 1994). In private banking, however, the category of special treatment should not be understood superficially. It is not limited to an elegant branch, a cup of coffee or a personalised card, but refers to the client's experience that the bank is able to recognise the complexity of their situation and take their preferences into account.

The customer experience perspective also makes it possible to view service quality as an experience distributed over time and across multiple touchpoints. Lemon and Verhoef emphasise that customer experience should be analysed across the entire customer journey, not only at a single transaction point (Lemon, Verhoef, 2016). In private banking, this means that the assessment of a meeting with an adviser begins before the client enters the branch: with the way the appointment is arranged, the quality of pre-meeting communication, information about the location, and the impression that the client is expected. It does not end when the conversation is over, but continues with the summary, the planning of next steps and the confirmation that the bank can translate the conversation into a concrete proposal for cooperation.

The importance of the client-bank relationship in the context of customer experience is also confirmed by Fernandes and Pinto, who showed that customer experience affects relationship quality and its outcomes in banking services (Fernandes, Pinto, 2019). In private banking, the dedicated adviser is a central element of the service model.

3. New conditions in private banking

Recent research indicates that private banking and wealth management are developing in an environment in which advisory relationships, personalisation and technological support for service delivery are gaining importance (Dzhaparov, 2024; Altrock et al., 2025). Dietzmann, Jaeggi and Alt, in their analysis of artificial intelligence (AI)-based support and automated advisory services (robo-advisory) in private banking, emphasised that such solutions can

support clients, increase advisers' flexibility, strengthen the client-adviser relationship in an omnichannel model and require advisers to develop new technical and analytical skills (Dietzmann et al., 2023). This conclusion is particularly important for private banking because it shows that technology need not displace the personal relationship. It can strengthen that relationship if it is designed as a tool for the adviser rather than as a substitute for advisory services. Research on robo-advisory in the banking sector points in the same direction. It suggests that models based solely on algorithms may be insufficient to meet clients' decision-making needs, whereas hybrid solutions that combine automation, process transparency and the possibility of human interaction have greater potential. From the perspective of private banking, technology should therefore be designed to support the adviser, streamline the client journey and reduce cognitive load, rather than to function as an autonomous substitute for the advisory relationship (Barile et al., 2024; Namyslo et al., 2025).

From the perspective of the private banking segment, it is also significant that younger client generations expect a different relationship model with the bank than previous generations. Research on the banking experience of younger clients in France highlights the importance of digitalisation, transparency, ease of contact and the alignment of banking services with lifestyle expectations (Kaabachi et al., 2022).

Similar conclusions are presented in the Mastercard report on the private banking market in Poland. The report, 'The Art of Banking: A Snapshot of the Private Banking Market in Poland', indicates that changing needs among high-net-worth clients are linked to generational change, growing openness to digital solutions and expectations of more personalised service (Mastercard, 2025). In its report on the UK private banking and wealth management sector, KPMG emphasises the economic importance of this segment and the role of wealth management institutions in providing investment, planning and advisory services to high-net-worth clients (KPMG UK, 2025). KPMG Switzerland, in turn, notes that Swiss private banks operate in an environment characterised by increasing complexity, competitive pressure, consolidation and the need to diversify services (KPMG Switzerland, 2025). The EY Global Wealth Research Report 2025 emphasises that wealth management clients' expectations go beyond access to products and include the quality of advice, digital tools, personalisation and the institution's ability to understand the client's situation (EY, 2025). Capgemini's World Wealth Report 2026 indicates that global HNWI wealth increased to USD 98.3 trillion by the end of 2025, while changing client expectations are transforming how advice is delivered, experienced and valued (Capgemini Research Institute, 2026). BCG, in its Global Wealth Report 2025, emphasises that the competitive advantage of wealth management institutions is increasingly driven by organic growth, clearer positioning, the ability to acquire clients, adviser training and the early engagement of successive generations of clients (Boston Consulting Group, 2025).

These observations are consistent with the findings of the authors' original research: private banking clients assess not only the offering, but also the bank's ability to transform the initial contact into an experience of a professional, personalised and technology-enabled relationship. The academic literature enables a broader interpretation of these changes than as a response to market expectations alone. Private banking and wealth management remain strongly relationship-based services, in which trust, personalised advice, continuity of contact and the adviser's ability to organise long-term financial cooperation are of central importance. At the same time, the sector operates under increasing pressure related to efficiency, costs and technology, which increases the importance of solutions that preserve the personal nature of the relationship while streamlining the service process (Dzhaparov, 2024).

The digitalisation of private banking should not be understood as the simple automation of client contact. A hybrid approach is more appropriate: technology supports the adviser, organises information, facilitates meeting preparation, increases process transparency and enables the relationship to continue after the meeting. This interpretation is consistent with the findings of the authors' original research (Institution of the Year, 2023-2025). Private banking clients assess not only the product range but also the bank's ability to transform the initial contact into a professional, personalised, and technology-supported relationship (Altrock et al., 2025; Barile et al., 2024).

4. Methodology of the original research

The empirical basis of this article is the authors' original research on the quality of private banking customer service conducted between 2023 and 2025 (Institution of the Year, 2023-2025). In each wave of the study, 10 banks offering private banking services were assessed. The study covered the following banks: Bank Pekao S.A., ING Bank Śląski S.A., Santander Bank Polska S.A., BNP Paribas Bank Polska S.A., mBank S.A., VeloBank S.A., Bank Millennium S.A., Powszechna Kasa Oszczędności Bank Polski Spółka Akcyjna, trading under the abbreviated name PKO Bank Polski S.A., Alior Bank S.A. and Bank Handlowy w Warszawie S.A. (operating under the Citi Handlowy brand). In each wave, each bank was assessed by 10 customers, with the same group of customers assessing all the banks included in the study. Consequently, 100 assessments were carried out each year, resulting in 300 assessments over the three years analysed. The project was conducted in the fourth quarter of each year, and each bank's score was calculated as the average of ratings relating to the customer's impression after contact with the bank. The assessment of contact with the bank covered 16 areas relating to the organisation of the initial contact, meeting preparation, the manner in which the client was received, the quality of the advisory discussion, needs identification, communication of the offer, explanation of regulatory requirements, presentation

of digital tools and organisation of follow-up steps after the meeting. The individual areas were used not primarily to compile a ranking of banks, but to identify the mechanisms shaping the perceived quality of service as the client enters the private banking segment.

The analytical framework used in the study was developed through a combined deductive-inductive procedure. The initial categories were derived deductively from the literature on service quality, relationship quality and customer experience in banking. Their final interpretation was then refined inductively based on recurring empirical observations from the three waves of mystery shopping research conducted in 2023-2025. Therefore, the seven dimensions proposed in the article should be understood as an analytical synthesis linking theoretical constructs with empirical patterns observed in the first-contact process, rather than as dimensions statistically derived from factor analysis.

The research scenario assumed that the client was a potential private banking client who had not previously used services in this segment. The client was interested in learning about the private banking offering, including investment opportunities, day-to-day banking, foreign exchange solutions, and other services related to everyday banking. In every interaction, the client expected answers to specific questions that were important to them, in addition to general information about the offering. In the 2024 and 2025 surveys, particular emphasis was placed on discussing investment opportunities, including investment products, and on the client's willingness to complete the MiFID II questionnaire if it was proposed or made a condition for a more detailed discussion of investment products.

Methodologically, the study may be classified as a repeatable mystery shopping study with elements of customer experience assessment. In the literature, mystery shopping is treated as a tool for measuring service delivery quality in real-life customer interaction scenarios (Wilson, 1998). The advantage of this method lies in the possibility of observing staff behaviour and the service process in a situation close to reality, rather than relying solely on self-reported accounts. At the same time, it should be emphasised that mystery shopping results do not constitute a classic representative survey of the opinions of the entire customer population. Their value lies in controlled observation of the process, comparability of scenarios, and the possibility of identifying specific service mechanisms (Finn, Kayandé, 1999). Mystery shopping served a similar function in earlier studies of service quality in the mortgage lending process, enabling comparisons between banks and mortgage brokers under heightened organisational uncertainty during the pandemic (Waliszewski, Łukaszewski, 2022).

In line with the approach of the European Banking Authority, mystery shopping may be used to assess service quality, the way in which financial products are offered, and the behaviour of financial institutions towards consumers, particularly at the pre-contractual stage (European Banking Authority, 2021). In the authors' study, the pre-contractual phase was particularly important: the potential client was only considering entry into the private banking segment, had not yet established a relationship with an adviser and was assessing whether the bank created conditions for continuing the relationship. This study design enables capture of

a key moment in relationship-based services: the transition from interest in the offer to an initial willingness to entrust part of one's financial affairs to the bank.

To clarify the empirical assumptions, Table 1 summarises the key characteristics of the three survey waves conducted between 2023 and 2025. The tabular presentation demonstrates comparability of the research design across successive years and indicates scenario changes resulting from the increased importance of investment discussions and the need to explain MiFID II requirements. Each year, the study covered the same type of client, a similar assessment structure and a consistent implementation period. This makes it possible to interpret the results not only year by year, but also as a basis for analysing changes in the quality of the initial contact over time.

Table 1.
Structure of the private banking service quality survey in 2023-2025

Survey component	2023	2024	2025
Number of banks surveyed	10	10	10
Number of ratings	100	100	100
Client type	Potential private banking client	Potential private banking client	Potential private banking client
Implementation date	Q4 2023	Q4 2024	Q4 2025
Number of assessment areas	16	16	16
Main scenario	Fund allocation, day-to-day banking, foreign exchange solutions	Fund allocation, day-to-day banking, foreign exchange solutions, and willingness to complete the MiFID II suitability questionnaire	Fund allocation, investment products, day-to-day banking, currency solutions, and willingness to complete a MiFID II suitability questionnaire
Nature of the research	Comparative customer-experience study	Comparative customer-experience study	Comparative customer-experience study

Source: own study based on original research conducted as part of the Institution of the Year project. (Instytucja Roku, 2023-2025).

The summary confirms that the study was repeatable and comparative. In each wave, 10 banks offering private banking services were assessed, yielding 100 evaluations of contact with the bank per wave and 300 evaluations across the entire period analysed. The consistent number of assessment areas and the similar profile of the potential private banking client strengthen the comparability of results across years. At the same time, the expansion of the study in 2024-2025 to include the client's willingness to discuss investment issues and complete the MiFID II questionnaire makes it possible to capture how regulatory requirements and the way they are communicated affect the perceived quality of service in the private banking segment.

5. Determinants of service quality in private banking

The first conclusion from the authors' research is that service quality in private banking is shaped before the actual advisory meeting takes place. A high standard of private banking should already be visible at the stage of booking the appointment, confirmation contact, forwarding details to the adviser, sending information about the location and welcoming the client at the branch. If the client has to find the private banking area on their own, ask for directions to the entrance, wait for a staff member or attempt to make contact several times, the promise of the premium segment is undermined before the advisory conversation begins. A similar importance of staff's initial reactions, identification of the purpose of the visit and presentation of remote channels was demonstrated in a study of the customer service process for customers opening an account at a bank branch during the pandemic (Matuszak-Flejszman, Łukaszewski, 2022b).

The first determinant of quality is the consistency of the contact journey (Bitner et al., 1990). Private banking does not begin with the meeting with an adviser, but with the moment when the customer attempts to contact the bank. If this stage is inefficient, the customer does not interpret it as a minor organisational error, but as a signal about the bank's service culture. In premium services, such signals carry greater weight than in mass-market services because the client expects a reduction in effort rather than the need to seek solutions independently.

The second determinant of service quality is the adviser. In private banking, the adviser does not function as a neutral intermediary between the client and the bank's offering. The adviser is the face of the institution, a guide through procedures and the primary source of trust. The authors' research shows that clients strongly link their assessment of the bank with their assessment of the adviser. If the adviser is well prepared, confident, able to explain the purpose of the private banking segment and clearly outlines their role, the client is more likely to perceive the bank as a professional institution. Conversely, if the adviser gives vague answers, avoids specific issues, hides behind regulations or fails to demonstrate expertise, the client questions not only the competence of the person conducting the conversation but also the value of the entire relationship with the bank. Expertise does not merely mean product knowledge. It means the ability to structure the conversation, identify the client's priorities, distinguish between primary and secondary issues, explain limitations and propose a way forward. An adviser perceived as an expert can demonstrate that private banking is not merely the name of a segment, but a way of organising the relationship with the client (Jurado et al., 2026). An adviser perceived as unprepared reduces a premium service to a sales presentation.

The third determinant of quality is trust. In private banking, trust is not built solely on the bank's brand. The brand may facilitate the initial contact, but it is not a substitute for the relationship with the adviser. Trust is built through interaction: the way questions are asked, the precision of answers, the transparency of information on costs and restrictions,

the willingness to acknowledge that a particular issue requires further clarification and the ability to outline next steps. The literature indicates that trust and satisfaction are key elements of relationships in banking services and may influence customer loyalty (Boonlertvanich, 2019). In private banking, this relationship appears to be particularly strong because the client assesses not only the current interaction but also a potential future relationship (Ho, Wong, 2023). In the authors' study, one of the key assessment criteria was the willingness to meet the same adviser again and the readiness to accept a private banking offer at a given bank. These two categories indicate that the client makes a prospective assessment: they consider whether a given person and institution could become their long-term financial partner. This perspective is confirmed by recent research on the adviser-client relationship in investment decisions, which shows that trust-building strategies influence investment decisions through the quality of the relationship with the adviser, with professionalism, transparency and the ability to understand the client's financial needs being particularly important (Kulal et al., 2024).

The fourth area determining service quality is the way in which regulatory requirements, particularly MiFID II, are communicated. The assessment of client suitability is one of the fundamental mechanisms of investor protection in the context of investment advice and portfolio management (European Securities and Markets Authority, 2022). However, the MiFID II procedure can be interpreted in two ways. It may be perceived as a sign of professionalism, concern for security and proper understanding of the client's needs. It may also be perceived by the client as a formalised barrier that prevents discussion of what matters most to them. The authors' research shows that the problem lies not in the MiFID II suitability questionnaire itself, but in the way in which it is integrated into the service process. If the adviser explains the purpose of the questionnaire, emphasises the importance of the risk profile and clarifies how the procedure will shape the remainder of the discussion, the client may perceive it as part of professional advice. If, by contrast, the adviser hides behind the procedure, postpones the discussion until the next meeting or states that without an account, they cannot discuss specifics, the client feels that time is being wasted and experiences a loss of agency. In such a case, a regulation designed to protect the client becomes, in the client's experience, a relational barrier.

The requirements of MiFID II should therefore be analysed not only as a regulatory obligation, but also as part of the client experience. High-quality service depends on the bank's ability to translate regulatory language into value language for the client. A similar conclusion emerges from the literature on the design of robo-advisory and digitally assisted financial advice. Transparency of information and processes, guiding the client through successive stages and reducing cognitive load are regarded as prerequisites for the acceptance of advisory solutions, particularly when the client is required to make decisions involving uncertainty, risk and financial consequences (Namyslo et al., 2025; Cardillo, Chiappini, 2024). The adviser should explain that assessing the client's investment experience, financial situation, investment objectives and risk tolerance is not intended to restrict the conversation, but to tailor it to the

client. In this sense, MiFID II may either strengthen trust if communicated as part of professional care or undermine it if communicated as a formal obstacle.

6. Changes in the quality of client relationships and advisory services in private banking between 2023 and 2025

A three-year analysis makes it possible to interpret the results beyond the assessment of individual meetings and to treat the study as a basis for identifying changes in the private banking service model. Between 2023 and 2025, a comparable research design was maintained: 10 banks offering private banking services were assessed, and 300 surveys were conducted. The scenario assumed that customers were interested in investing their funds, day-to-day banking, foreign exchange solutions and the availability of other financial services. This design makes it possible to analyse not only the level of service quality in a given year, but also the stability and variability of standards over time.

To summarise the survey results, Figure 1 shows changes in the banks' positions in the private banking service quality ranking between 2023 and 2025. This overview is supplementary, as the aim of the article is not to rank banks as such, but to identify the mechanisms shaping the quality of the initial contact with a potential private banking client. Nevertheless, the ranking provides a concise illustration of the stability or variability of individual institutions' positions across successive waves of the study.

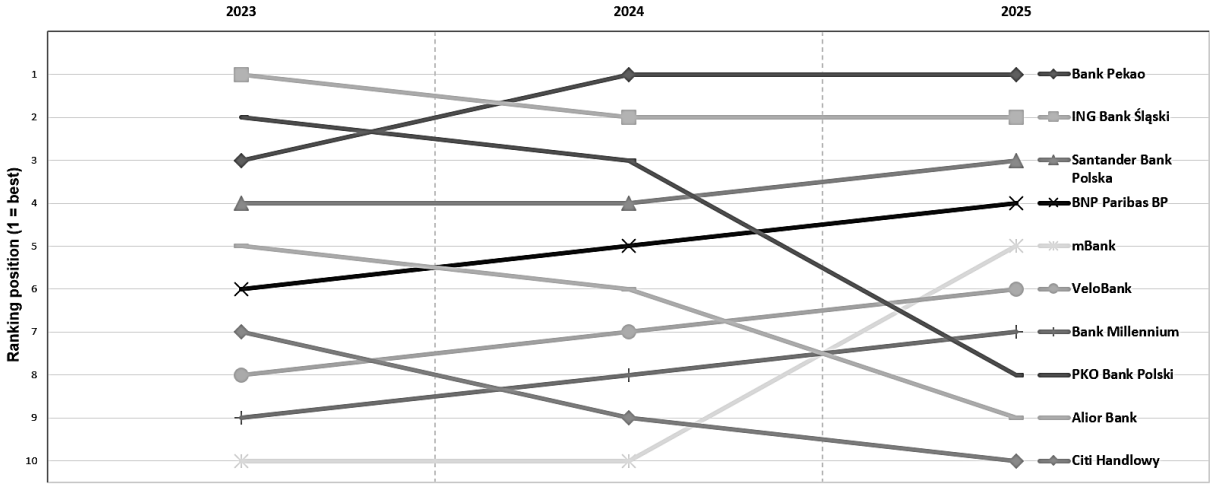

Figure 1. Banks' positions in the private banking service quality ranking, 2023-2025.

Source: own study based on original research conducted as part of the Institution of the Year project (Instytucja Roku, 2023-2025).

The ranking shown in Figure 1 was calculated based on the annual bank-level service quality score. This score was calculated as the average of 10 mystery shopping assessments conducted for each bank in a given year. Each assessment covered the same 16 areas of service

quality relating to the first contact with a potential private banking client. Banks were ordered from the highest to the lowest annual score, where position 1 denotes the highest result in a given year. In this article, the ranking is used solely as a synthetic illustration of changes over time. The main purpose of the analysis is not to classify banks, but to identify the mechanisms shaping perceived service quality. The first area of change concerns the overall quality of meetings. In 2023, 49% of meetings were rated at 80% or above; in 2024, this percentage increased to 58%, while in 2025 it stood at 52%. This indicates that the improvement in service quality was not linear. The increase observed in 2024 was not fully maintained in 2025, suggesting that service quality in private banking depends not only on formal standards but also on their consistent implementation by advisers and branches. From an academic perspective, the key issue is therefore not merely a comparison of banks' results, but the identification of variability in service quality over time.

The second area of change concerns technological preparation for the initial contact. The study highlights elements that constitute digital touchpoints: a contact form, an autoresponder, a text message with meeting details, an adviser's digital business card, an email with directions, a follow-up message after the meeting and the possibility of a video call. These elements are not merely technical additions to the service. In the private banking segment, they function as indicators of quality. The client assesses whether the bank can guide them efficiently through the first stage of the relationship and minimise their organisational effort. If the contact requires repeated requests, movement through inappropriate channels or the need to establish basic information independently, the service loses some of its premium attributes even before the advisory conversation begins.

The third area of change concerns the way in which advisers combine relationship-building conversation with an explanation of the tools available to the client after the meeting. In 2023, information about digital tools was often general and presented as part of everyday banking services. In 2024, conversations more frequently included specific examples of functions useful to private banking clients, such as card services, currency exchange, contact with the bank, authorisation, limit management and access to product information. This interpretation is supported by earlier research on mobile banking in Polish commercial banks, which showed that mobile applications had become an important customer service channel and, in selected service processes, could replace direct contact with the bank without additional support from an adviser (Matuszak-Flejszman, Łukaszewski, 2022a). In private banking, however, this role should be interpreted as complementary to the advisory relationship rather than as a substitute for the adviser.

In 2025, knowledge of these tools became more clearly linked to the assessment of adviser preparedness. This does not mean, however, that technology became the sole determinant of private banking quality (Mainardes, Freitas, 2023). Its significance lay rather in the fact that the client assessed whether the adviser could demonstrate consistency between the face-to-face conversation and the subsequent day-to-day management of the relationship with the bank.

A similar conclusion emerges from research on the quality of mortgage lending in Polish banks, where digitalisation was not treated as a standalone substitute for advisory services, but as a factor that organises, accelerates and facilitates customer service within the lending process (Waliszewski, Łukaszewski, 2025).

The fourth area of change concerns the relationship between technology and investment regulation. In the 2024 study, the issue of the MiFID II questionnaire was particularly visible. In most cases, the questionnaire could not be completed without first opening an account or undergoing an additional procedure. In practice, this meant that a client interested in discussing the investment of their funds was not always able to have a fully developed investment discussion during the first meeting. From the perspective of service quality, the problem did not lie in the existence of regulatory requirements as such, but in the absence of a process that would prepare the client for the discussion in advance. The possibility of sending a personalised link to the questionnaire before the meeting could reduce wasted time, make the discussion more personalised and enable the adviser to prepare a better proposal.

The fifth area for improvement concerns maintaining the relationship after the meeting. Private banking should not be treated as a one-off presentation of an offer, but as a process of relationship building. A post-meeting email is therefore important because it summarises arrangements, provides materials, outlines next steps and announces the next point of contact. Technology can strengthen the relationship in this area because it enables continuous contact, organises information and reduces the risk that the meeting will remain a general discussion without being translated into a client decision (Capgemini, 2024).

A summary of the most significant changes observed across successive waves of the study is presented in Table 2. This overview makes it possible to compare not only service quality ratings in individual years, but also changes in digital support for client relationships, communication of MiFID II requirements and follow-up contact after the meeting.

Table 2.
Changes in selected aspects of private banking service quality, 2023-2025

Indicator/area	2023	2024	2025	Interpretation
Meetings rated at 80% or above	49%	58%	52%	Improvement in 2024 and partial reversal in 2025; quality is not linear
Meetings rated at 100%	1	5	7	Increase in the number of very good experiences, despite fluctuations in the overall quality level
Number of banks scoring at least 80%	5	4	4	A relatively small group of banks meeting high standards
Digital support for follow-up after the meeting	Available, but often discussed in general terms	A wider range of day-to-day banking functions	A factor in assessing an adviser's competence	Digital tools reinforce the assessment of adviser preparedness while remaining a supporting element of the relationship

Cont. table 2.

Communication of MiFID II requirements and the investment consultation	This element had not yet been clearly identified in the survey scenario	Absence of a process for completing the questionnaire before the meeting, or without an account	A greater prominence of information on MiFID II, but continued formalisation of the process	Regulation is becoming a test of the quality of the bank's communication and technological capabilities
Post-meeting communication and relationship management	Varied practices	The growing importance of email and summaries	An element of the expected professionalisation of the relationship	The quality of private banking requires ongoing contact after the meeting

Source: own study based on research conducted as part of the Institution of the Year project, 2023-2025 (Instytucja Roku, 2023-2025).

The data presented in Table 2 indicate that service quality in private banking did not change linearly between 2023 and 2025. The increase in the proportion of meetings rated at 80% or above in 2024 was not fully maintained in 2025, despite an increase in the number of experiences rated at the highest level. This means that, in private banking, the presence of high standards is not sufficient; their consistency across interactions, advisers and banks is also crucial. At the same time, the table shows the growing importance of elements that support the relationship, such as post-meeting communication, digital preparation for the interaction and the way in which MiFID II requirements are explained.

The findings from the three-year analysis indicate that, in private banking, technology does not replace the adviser, but is becoming a prerequisite for a high-quality advisory relationship. Clients still expect expert conversation, trust and a personalised approach; however, they also expect the bank to use digital tools to prepare for meetings, explain the offering, simplify formalities, support day-to-day banking and maintain contact. Seen in this light, mobile banking and digital solutions are not a channel separate from private banking, but rather the infrastructure underpinning service quality in the premium segment.

7. A model of technology-supported relationship-based and advisory quality

Based on the literature and the authors' original research, it is possible to propose a model of technology-supported relationship-based and advisory quality in private banking. The model has a combined deductive-inductive character. Deductively, its dimensions refer to concepts developed in the literature on service quality, relationship quality, customer experience and hybrid advisory models. Inductively, they were refined based on recurring observations from the authors' mystery-shopping research, particularly those concerning contact preparation, premium-service symbolism, adviser expertise, needs identification, regulatory communication, digital support, and post-meeting follow-up. The model therefore assumes that

perceived service quality arises from a combination of seven analytically distinguished dimensions: accessibility and contact preparation, the symbolism of a premium service, adviser expertise, relationship-based needs assessment, regulatory and investment communication, technological support for the relationship and the ability to plan further cooperation. Figure 2 illustrates the model of technology-supported relationship-advisory quality in private banking.

The interrelationships between these dimensions of service quality can be captured in a sequential model in which successive stages of the client's interaction with the bank contribute to a cumulative relationship- and advisory-based experience. This model is presented in Figure 2. Its core premise is that perceived service quality in private banking does not arise solely during the conversation with an adviser. It is shaped already at the stage of organising contact and is subsequently reinforced or weakened by the way in which the conversation is conducted, regulatory communication is provided, digital tools are used, and the relationship is continued after the meeting.

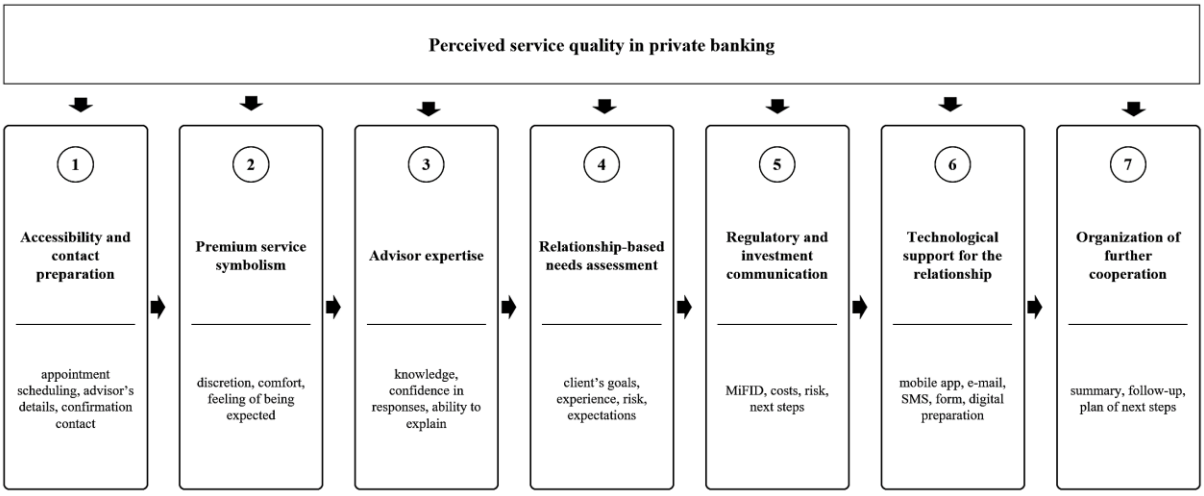

Figure 2. Technology-supported relationship-advisory quality model in private banking.

Source: compiled by the authors based on their own research as part of the Institution of the Year project (Instytucja Roku, 2023-2025).

Figure 2 organises the main elements of service quality into a process-based framework. It shows that the private banking client experience is sequential: it begins with accessibility and contact preparation, then includes the symbolism of a premium service, adviser expertise, needs identification and regulatory and investment communication, and concludes with technological support for the relationship and the organisation of further cooperation. To clarify the meaning of the individual elements of the model, Table 3 presents their interpretation from the client's perspective, together with examples of high-quality service.

Table 3.
Characteristics of the dimensions of relationship-based and advisory quality in private banking

Quality dimension	Significance for the client	Manifestation of high quality
Accessibility and contact preparation	The client assesses whether the bank is ready for the relationship	Effortless appointment booking, adviser's details, directions, confirmation message
Symbolism of a premium service	The client recognises whether this segment truly differs from the mass-market service	Private space, professional welcome, comfort, sense of being expected
Adviser expertise	The client assesses whether they can trust the person managing the relationship	Knowledge, confidence in answers, experience, qualifications and ability to explain
Needs identification	The client expects a personalised approach, not a standard presentation	Questions about objectives, experience, risk, investment expectations and the nature of the working relationship
Regulatory and investment communication	The client wants to understand limitations and opportunities	Clear explanation of MiFID II, costs, risks, the scope of the discussion and next steps
Technological support for the relationship	The client expects efficiency and a reduction in formal burden	Mobile application, online form, email, text message, digital business card, digital data processing
Organisation of further cooperation	The client assesses whether the conversation will lead to a relationship	Summary, plan of next steps, follow-up after the meeting, introduction to the support team

Source: own study.

Table 3 expands the model presented in Figure 2 by showing how the individual dimensions of relationship-based and advisory quality can be identified in the practice of private banking customer service. The table shows that high-quality service does not result from a single element of contact with the bank, but from the coherent integration of these elements across the customer journey. Efficient appointment scheduling, a professional welcome, adviser expertise, a personalised conversation, a clear explanation of MiFID II requirements, the use of digital tools and the planning of follow-up actions together create an experience that the client may interpret as a professional and trustworthy relationship with the bank. The model presented in Figure 2 and elaborated in Table 3, therefore, demonstrates that service quality in private banking is processual and cumulative. It begins before the meeting with the adviser, encompasses the advisory conversation and the way in which regulatory requirements are communicated, and is then reinforced or weakened by the organisation of further cooperation. For this reason, it is important not only to define the dimensions of relational and advisory quality, but also to identify the mechanisms through which these dimensions are manifested in the practice of the client's first contact with the bank. The mechanisms for building the quality of the first contact in private banking are presented in Table 4.

Table 4.
Mechanisms for building the quality of the initial contact in private banking

Quality mechanism	Significance for the client	Manifestation of high-quality service
Preparation for the interaction	The client assesses whether the bank is ready to begin the relationship and treats them as an expected discussion partner.	Efficient meeting arrangement, confirmation of the date, provision of the adviser's contact details, clear indication of the meeting venue and minimisation of the customer's need to resolve organisational issues independently.
Professional welcome	The client assesses whether the standard of service fulfils the promise of the private banking segment.	Punctual reception, discreet meeting space, a sense of being welcomed, a well-organised start to the meeting and maintenance of a premium standard without excessive formality.
Adviser expertise	The client assesses whether the adviser can act as a long-term financial partner.	Confidence in responses, knowledge of the product range, experience, ability to explain complex issues, ability to structure the conversation, and to indicate the benefits of further cooperation.
Needs identification	The client expects a personalised conversation rather than a standard product presentation.	Questions about financial goals, investment horizon, experience, expectations of the bank, preferred method of contact, currency, liquidity and investment needs.
Building trust	The client assesses whether the bank and the adviser are trustworthy, predictable and committed to a long-term relationship.	Transparency of information, consistency of communication, avoidance of an overly sales-oriented approach, willingness to explain limitations and clear presentation of the adviser's role in ongoing service.
Regulatory communication	The client wants to understand the purpose of formal requirements, including the MiFID II questionnaire, risk profile and limitations of the investment discussion.	Explanation of the purpose of the MiFID II questionnaire, linking regulation to client protection, outlining next steps and presenting formal requirements as part of professional service rather than a barrier to discussion.
Managing the client's time	The client expects organisational and cognitive effort to be minimised.	Well-structured meeting, no repetition of the same information, clear transitions between topics, specific answers and indication of which matters can be addressed immediately and which require a further step.
Follow-up after the meeting	The client assesses whether the conversation leads to genuine further cooperation or remains merely a presentation of an offer.	Summary of findings, provision of materials, announcement of follow-up contact, indication of next steps, possibility of contacting the advisor, and maintaining continuity of communication after the meeting.

Source: own study.

The overview presented in Table 4 shows that high-quality initial contact in private banking requires consistency across organisational, relational, advisory and communication activities. The client assesses not only the adviser's competence, but also the bank's preparation for the meeting, the manner of reception, the ability to identify needs, the transparency of regulatory communication and the capacity to plan further steps. The continuity of the client experience is particularly important: inefficiency at the stage of arranging a meeting may undermine the assessment of the entire relationship, while professional follow-up after the meeting may strengthen the feeling that the bank treats the relationship as a long-term one. In this context, the quality of private banking is not limited to the standard of the meeting itself, but encompasses the entire journey through which the client enters into a relationship with the bank.

8. Discussion and limitations of the study

The results of the authors' research indicate that an analysis of service quality in private banking should focus not only on comparing banks' performance but, above all, on the mechanisms through which the client recognises the bank's professionalism, expertise and willingness to maintain the relationship. This finding develops the classical understanding of service quality by showing that, in private banking, reliability, assurance, responsiveness and empathy acquire a specifically advisory and relational meaning (Parasuraman et al., 1988). Assurance is not limited to professional appearance or polite behaviour, but is expressed in the adviser's ability to reduce the client's uncertainty, explain complex issues and create a sense of expert support. Empathy, in turn, is not only kindness, but the ability to recognise the client's financial goals, investment experience and expectations regarding the future relationship.

The findings are also consistent with the technical-functional approach to service quality proposed by Grönroos (1984). In private banking, technical quality concerns access to investment, banking and foreign exchange solutions, whereas functional quality determines whether the client perceives the service as professional, trustworthy and personalised. The present study confirms the relevance of this distinction and also shows that in private banking, functional quality is strongly mediated by the adviser. The client does not assess the bank's offer in isolation but through the way the adviser explains, personalises and organises it.

This interpretation is consistent with earlier research on private banking, which indicates that customer satisfaction in this segment depends not only on the value of the service but also on the private banker's role as the relationship manager (Lassar et al., 2000; Seiler, Rudolf, 2014). The present study extends this perspective by showing that the relationship is assessed already at the first point of contact, before the client decides whether to continue cooperation with the bank. It also confirms the importance of customer experience understood as a process distributed across several touchpoints rather than a single service encounter (Lemon & Verhoef, 2016; Fernandes, Pinto, 2019).

The findings are consistent with earlier research on banking products that require detailed explanations of terms, restrictions, and further steps in the relationship, including the process of opening a child's account (Matuszak-Flejszman, Łukaszewski, 2025). In both cases, service quality depends not only on the availability of the product, but on the ability of bank staff to guide the client through the process, reduce uncertainty and translate formal requirements into understandable information. The difference is that in private banking, this mechanism is more strongly connected to trust, adviser expertise, and the client's willingness to enter into a long-term financial relationship.

Compared with recent research on digitalisation, robo-advisory and hybrid advisory models, the study shows that technology is important, but not autonomous. Digital tools improve the customer experience by reducing effort, supporting preparation for the meeting,

organising follow-up, and facilitating continuity of contact. They do not, however, replace the private banker's relational and advisory role. This finding nuances the discussion of digital transformation in wealth management: in the premium segment, technology creates value primarily when it strengthens human relationships rather than when it substitutes for them (Dzhaparov, 2024; Altrock et al., 2025; Barile et al., 2024; Namyslo et al., 2025).

A further theoretical implication concerns the role of regulation in customer experience. MiFID II requirements are usually analysed as a compliance obligation or investor-protection mechanism (European Securities, Markets Authority, 2022). The present study shows that they also function as a service quality touchpoint. When the suitability questionnaire and risk-profile assessment are explained as elements of client protection, they strengthen perceived professionalism. When they are presented mainly as a formal obstacle, they weaken the client's sense of agency and reduce the perceived quality of the interaction. This means that regulatory compliance should not be separated from service quality management, but integrated into the design of the advisory process.

The non-linear changes observed between 2023 and 2025 also have theoretical significance. The improvement in 2024 and partial reversal in 2025 suggest that high service quality in private banking is not achieved once and for all through formal standards. It requires consistent implementation across advisers, branches and stages of the customer journey. This conclusion is consistent with recent market observations indicating that private banking and wealth management are under increasing pressure regarding client expectations, adviser productivity, personalisation, and technology-enabled service models (ZEB Consulting, 2025). At the same time, the authors' research shows that the fundamental issue in service quality remains relational: the client assesses whether the adviser can translate the complexity of the offering, regulation and process into a clear, cooperative and professional conversation.

The study has several limitations that should be taken into account when interpreting the results. First, it is not a representative survey of all private banking clients but rather a controlled mystery-shopping study based on a predefined scenario. Second, it concerns potential clients at the entry stage of the relationship, not existing clients with a long-term history of cooperation with a private banker. Third, the results may be influenced by the individual adviser, the branch location, the time of contact, and the organisational context of a specific meeting. Fourth, although the study covers three annual waves, it does not follow the same set of real clients over time and therefore does not measure the longitudinal development of relationship quality. Fifth, the assessment captures the quality of the first-contact process, but does not measure subsequent investment performance, client retention or long-term satisfaction. These limitations mean that the findings should be interpreted as evidence of service mechanisms observable at the entry point to private banking, rather than as a full assessment of the private banking relationship as a whole.

9. Conclusions

Based on the analysis, several key conclusions may be drawn.

Service quality in private banking is relationship- and advisory-based. It is not simply the sum of the quality of products, branches and processes, but an experience in which the adviser plays a central role.

An adviser's expertise is one of the most important factors in building trust. The client expects not only product knowledge, but also the ability to conduct a conversation, identify needs, explain limitations and plan further cooperation.

The initial stages of the customer journey are of strategic importance. Appointment arrangement, pre-visit contact, the manner in which the customer is received, and the organisation of the space all influence the customer's assessment of the bank before the discussion of the offering begins.

MiFID II and other regulatory requirements should be treated as part of the customer experience. Regulations may reinforce a sense of professionalism if they are communicated clearly and in a spirit of partnership, or undermine relationship quality if they are presented as a barrier.

Digital tools support service quality in private banking, but they do not replace the advisory relationship. Their significance lies primarily in streamlining preparation for the meeting, reducing the client's organisational burden, organising next steps and maintaining relationship continuity after the meeting.

A three-year research perspective shows that service quality does not develop linearly. The study provides new knowledge by showing that the quality of private banking is not created by a single service element, but by a sequence of mutually reinforcing interactions. The first contact with a potential private banking client should therefore be treated as a strategic stage of relationship formation. The findings show that adviser expertise, regulatory communication, digital support and post-meeting follow-up jointly determine whether the client interprets the first contact as the beginning of a professional advisory relationship.

Between 2023 and 2025, both improvements and setbacks were visible, which means that high-quality private banking requires not only a high standard but, above all, consistent delivery.

In private banking, service quality is shaped by the combination of expertise, trust and client experience, while increasingly requiring technological support.

The importance of the study goes beyond the assessment of individual banks. For research on service quality, the article demonstrates the value of combining mystery-shopping data with a mechanism-oriented interpretation of customer experience in relationship-based financial services. For banking practice, the findings may be used to improve adviser training, appointment organisation, MiFID II communication, digital preparation for meetings and

follow-up procedures. The results may also support the design of hybrid advisory models in which digital tools enhance, rather than replace, personal advice.

A bank's competitive advantage in the private banking segment stems not only from the scope of its offering, but from its ability to transform the initial contact into the beginning of a professional, partnership-based and technologically supported advisory relationship.

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A MATURITY MODEL FOR HOSPITAL DEPARTMENT DIGITALISATION: DESIGN AND EXPERT VALIDATION

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Purpose: The purpose of this paper is to present a maturity model for healthcare digitalisation processes at the hospital ward level. The model is intended to support self-assessment of wards and facilitate both internal and external benchmarking. Identifying strengths and areas for improvement can help develop and implement digitalisation initiatives tailored to the specific characteristics of different types of hospital wards.
Design/methodology/approach: The maturity model was developed using Becker et al.'s methodology, which provides a systematic and scientifically rigorous framework for maturity model design. The development process included multiple stages of model construction and iterative validation conducted by domain experts, ensuring the consistency, relevance, and practical applicability of the proposed solution.
Findings: The article presents the complete structure of the maturity model, comprising five maturity levels and 20 assessment areas grouped into three perspectives: qualitative, organisational, and technical. In addition to defining the model structure, the paper specifies assessment criteria and reference points for each perspective, enabling the identification of low, medium, and high levels of maturity. The model therefore provides a comprehensive framework for evaluating both the implementation and practical use of information technologies within hospital wards.
Research limitations/implications: The validation process at all stages of model development relied exclusively on experts from Polish hospitals. Although the experts represented different healthcare organisations, the findings may reflect the specific context of the Polish healthcare system and may require further validation in other countries and healthcare settings.
Practical implications: The model provides hospital ward managers and healthcare professionals with a practical self-assessment tool to support improvement planning, investment decision-making, and the coordination of digitalisation activities across hospital departments.
Social implications: Improved digitalisation of healthcare processes may enhance accessibility and quality of medical services by enabling more effective use of information technology in clinical practice.
Originality/value: The originality of the proposed model lies in its focus on the hospital ward level. Unlike existing maturity models that assess digitalisation at the level of entire hospitals,

the proposed approach addresses the specific characteristics, processes, and digitalisation needs of individual wards.
Keywords: Maturity Model, Digital Maturity, Hospital Department, Health Information System, Strategic Planning.
Category of the paper: Research paper.

1. Introduction

Thanks to information technology, new opportunities are emerging to improve the quality of life. Its implementation enhances the effectiveness of organisational activities. It is recognised as a key tool for improving quality and accessibility in healthcare, demonstrating both administrative and medical benefits of hospital digitalisation (Barłóg, Mendryk, 2025; Sætra, Fosch-Villaronga, 2021). Digitalisation is considered one of the most effective responses to stakeholder pressure to improve healthcare quality and reduce costs (Saifudin et al., 2021). It involves the use of digital technologies—such as mobile devices, applications, artificial intelligence, and data analytics—to enhance healthcare delivery, diagnosis, patient monitoring, and overall quality of life. It encompasses a wide range of activities, from electronic health records and telemedicine to health-monitoring apps, wearable tracking devices, and other innovations (Woods et al., 2023).

Hospital digitalisation can be considered effective when it improves the quality of care, reduces costs through streamlined administrative processes, and ensures data confidentiality and security (Rachid et al., 2024). However, despite managerial efforts, hospitals have not achieved the same level of digital success as other industries, such as finance or retail (Khuntia et al., 2024). Many healthcare digitalisation projects have failed to meet expectations (Agarwal et al., 2010; Preko, Boateng, 2020). The main reasons include high organisational complexity, multiple decision-making levels, inconsistent procedures, and diverse staff competencies and roles (Hellstrand Tang et al., 2024; Krawczyk-Sołtys, Płatkowska-Prokopczyk, 2024). This causes problems in managing the digitalisation of hospitals, which is seen as the implementation of changes like process innovations, often even breakthrough ones (Bygstad, Øvrelid, 2020). Moreover, hospitals' structures may create local bottlenecks that hinder information flow (Winasti, Berden, van Merode, 2023).

Maturity models can help overcome these challenges, as they are widely used to assess and improve business processes and organisational performance. Their key principle is progression through successive stages—from basic to optimised maturity levels (Gomes, Romão, 2018; Knosp et al., 2018). In healthcare, such models assist managers in guiding complex digital transformation initiatives, fostering engagement, supporting organisational learning, and enabling systematic evaluation of outcomes (Bititci et al., 2015; Menukhin et al., 2025). Although critics note that digital transformation does not always follow a linear path (Teichert,

2019), maturity models remain valuable tools for understanding and supporting management practices (Carvalho et al., 2019; Ochoa-Urrego, Peña-Reyes, 2021).

Existing hospital maturity models—such as the Hospital Information System Maturity Model (HiSMM), NHS Infrastructure Maturity Model (NIMM), Telemedicine Service Maturity Model (TMSMM), and Electronic Medical Record Adoption Model (EMRAM)—focus on the hospital as a whole rather than on individual units. Yet, departments differ considerably in work characteristics, information needs, and IT use. To address this gap, this article presents a model for assessing the maturity of hospital department digitalisation, following the approach of Jäkel et al. (2024).

The proposed approach allows managers to view the hospital's digitalisation process through the lens of its individual departments. This enables the detection of so-called "bottlenecks" resulting from, among other things, differences in staff digital competencies, equipment availability, or work organisation. Since departments (e.g., surgical, internal medicine, pediatric) differ significantly in their work nature, information needs, and use of IT systems, a maturity model at the hospital level is often too general. This is especially true since developing local solutions in the design of IT systems promotes their actual use by users (Wiesche et al., 2024). Our model serves as a self-assessment tool that helps managers diagnose problems and identify appropriate solutions, such as integration with medical devices, training programs, workflow optimisation, patient data management, or system interface design. In this paper, we consciously employ the term 'digitalisation' rather than 'computerisation', as the proposed model extends beyond basic IT infrastructure installation to encompass advanced data utilisation, artificial intelligence, predictive analytics, and systemic integration within HIS.

The subsequent part of the article presents the theoretical foundations of maturity models and the existing approaches used in healthcare. Next, the methodology for developing the proposed model and its detailed characteristics is described. The following section concerns the results of expert verification, based on which the model's validity and utility were assessed. The discussion highlights its practical significance, application possibilities, and limitations. The article concludes with findings and recommendations on further research directions and the model's potential use in hospital management practice.

2. Digital maturity models in healthcare

2.1. The essence and application of maturity models

Maturity models are widely used to evaluate and improve business processes and selected areas of organisational functioning. The key principle of their construction is the progression through successive stages of development—from a basic level to increasingly advanced and

optimised states (Knosp et al., 2018). Gradually increasing maturity represents a path to improvement as the organisation evolves toward a desired future state.

Models of this type have found application in many sectors, including education, energy, finance, public administration, manufacturing, and healthcare (Li, Lau, 2019). A special category comprises Digital Maturity Models (DMMs), which enable measurement of digitalisation levels and support planning for an organisation's digital transformation (Haryanti et al., 2024).

2.2. Evaluating the utility of maturity models

Maturity models define hierarchically ordered levels of advancement, identifying characteristic practices and competencies. Consequently, organisations can diagnose their current situation and plan directions for improvement (Vargas et al., 2023). In healthcare, such models support managers in overseeing complex digitalisation initiatives (Menukhin et al., 2025).

The advantages of these models include, among others, stimulating management engagement, facilitating organisational learning, and providing a tool for systematic performance assessment (Bititci et al., 2015). At the same time, critics emphasise that the complexity of digital transformation cannot always be reduced to a linear sequence of stages and that there is no universal path for digital development (Teichert, 2019). However, assuming that a model is a simplification primarily intended to support better understanding and practical management, its value of application can be recognised (Carvalho et al., 2019; Ochoa-Urrego, Peña-Reyes, 2021).

2.3. Maturity models in healthcare

In recent years, numerous maturity models have been developed in the healthcare sector, although they remain at a relatively early stage (Vargas et al., 2023). Among the most frequently discussed are:

- Electronic Medical Record Adoption Model (EMRAM) – an eight-stage model developed by HIMSS, used to assess the advancement of electronic medical record implementation, considering system integration, security, and the use of clinical decision support tools (Najjar et al., 2021).
- Hospital Information System Maturity Model (HiSMM) – assesses the maturity of hospital information systems and staff competencies in their use, distinguishing six levels of development (Gastaldi et al., 2018).
- Healthcare Usability Maturity Model (UMM) – enables the assessment and improvement of IT system usability in healthcare, ranging from a lack of formal practices to their full optimisation (Carvalho et al., 2018).

- Informatics Capability Maturity Model (ICMM) – evaluates an organisation's capabilities in the use of medical informatics based on five development levels—from basic to innovative excellence (Gomes, Romão, 2018).
- Business Intelligence Maturity Model (BIMM) – used to assess the extent of business intelligence tool utilization in healthcare organizations, covering five levels from ad hoc solutions to full optimization (Gastaldi et al., 2018).

In addition to the above, other approaches have also been developed, such as the Digital Health Communication Maturity Model (DHCMM) (Kim, Namkoong, 2025), the Telemedicine Service Maturity Model (TMSMM) (Van Dyk, Schutte, 2013), and models related to demand and capacity management in healthcare facilities (Myrberg et al., 2024).

2.4. Research gap and the need for a new approach

Existing maturity models primarily focus on the institution as a whole. In practice, however, hospital departments differ significantly in the nature of their work, their information needs, and their use of IT systems. There is a lack of a tool to diagnose diversification between units within the hospital.

The maturity model for hospital department digitalisation proposed in this article aims to fill this gap. Its essence is to enable managers to assess the degree of digitalisation at the departmental level, enabling better problem identification, detection of "bottlenecks", and more precise improvement actions.

3. Research methodology

The maturity model for hospital department digitalisation processes was developed in accordance with the methodology proposed by Becker et al. (2009). The individual stages of the research approach are presented in Figure 1.

The model's development originated from the need to support the University Clinical Hospital (UCH) in Opole's digitalisation process. The project was carried out in collaboration with the Hospital Director and a team of researchers from the Faculty of Economics and Management at Opole University of Technology, enabling validation by both practitioners and the academic community. Expert validation was conducted at several stages: during the definition of maturity dimensions and aspects (Stage 3), throughout the iterative model design process (Stage 5), and during validation in selected departments of the UCH in Opole (Stage 6).

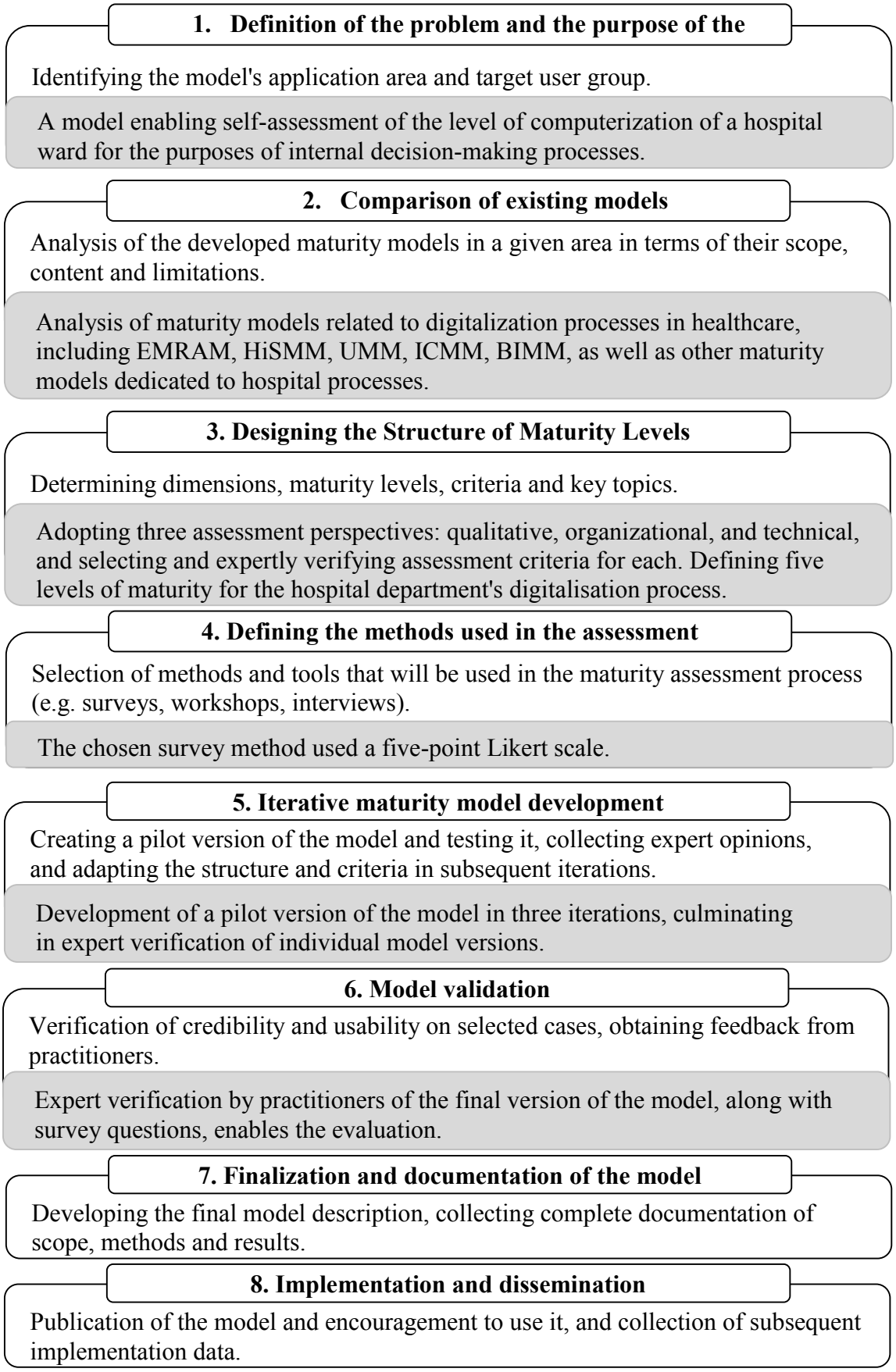

Figure 1. Methodology for developing a maturity model of digitalisation processes in hospital departments.

3.1. Initial verification

The first significant verification occurred during the phase in which dimensions, maturity levels, and evaluation criteria were defined. A three-step approach was adopted:

1. consultations with scientific experts who participated in the model development and literature analysis,
2. verification by practitioners – directors of eleven clinical hospitals in Poland,
3. presentation of the preliminary version of the model structure at the 10th International Conference "Knowledge and Information Technologies in Creating Entrepreneurship", combined with the 4th Congress of Economic Informatics (October 2023, Poland).

3.2. Design and detailed verification

To ensure high validity and reliability of the developed model, a rigorous multi-stage expert validation process was conducted during the design stage, involving a total of 25 specialists: 13 independent external experts and 6 internal validators during the thematic validation phase, and another 6 internal validators in the questionnaire build stage.

A purposive sampling strategy was used to recruit 13 external experts, based on a strict alignment between their verified professional competencies and the model's specific dimensions. To ensure objective assessment and prevent bias, all 13 external experts were fully independent and had no professional or hierarchical subordination to the research team.

Due to the complexity of the multi-stage verification and the difficulty of recruiting high-level specialists for a comprehensive, overarching review, the evaluation scope was strictly divided into distinct thematic streams. Each expert evaluated only the components directly matching their domain of expertise, which effectively eliminated the risk of evaluative overlap between groups. The verification was conducted across three perspectives: qualitative, organisational, and technical (Table 1). Each group of experts assessed only the areas consistent with their professional competencies.

Table 1.
Participation of experts in verifying the model at the design stage

Qualitative perspective	Organizational perspective	Technical perspective
Assessment by seven experts, including two from the UCH in Opole. • Healthcare quality specialists – individuals responsible for audits, ISO standards, and hospital accreditations. • Personal data protection experts (GDPR) – specialists in data processing compliance with legal regulations. • Clinicians with IT experience – doctors and nurses with practical experience using IT systems and their impact on the quality of care.	Assessment by six experts, including two from the UCH in Opole. • Healthcare managers – individuals managing hospitals or departments, familiar with organisational and administrative challenges. • Project management specialists – especially those with experience in healthcare or IT system implementation. • Change management experts – especially those with experience implementing technology in medical facilities.	Assessment by six experts, including two from the UCH in Opole. • Medical IT specialists - individuals involved in the design, implementation, and maintenance of IT systems in hospitals. • IT system architects - specialists in IT infrastructure and system integration. • Cybersecurity specialists - individuals responsible for data security in medical facilities.

The updated model underwent additional verification by 6 experts at the UCH in Opole. Each of the six participants received a full version of the model, encompassing all three perspectives, with questions formulated for each criterion. The set of questions was then reviewed again, this time to ensure its adequacy and to assess the branch management's ability to conduct a self-assessment without external auditors.

3.3. Final validation

In the final validation phase, an empirical study was conducted to assess the maturity of digitalisation processes using the proposed model. The study involved a multidisciplinary cohort of 59 respondents, representing every hospital department, primarily clinicians - including physicians, nurses, technicians, and medical secretaries—as well as administrative staff and IT specialists. During this verification stage, participants were also asked to evaluate the model's structure for validity and comprehensiveness as a measurement tool.

4. Maturity model of digitalisation processes in hospital departments

4.1. Model structure

The final version of the hospital department digitalisation maturity model encompasses three complementary perspectives: qualitative, organisational, and technical. Each perspective is defined by a set of 6-7 criteria, each with detailed benchmarks for assessment. The model is based on a five-level maturity scale (Table 2), with levels arranged hierarchically - from fragmented, characterised by a lack of systematic IT support, to excellent, where the department utilises advanced analytics, artificial intelligence tools, and a proactive approach to process improvement.

Table 2.
Characteristics of maturity levels

Level name	Characteristic
Fragmentary	Lack of systematic IT support, dominance of paper processes and ad hoc activities.
Basic	Partial, limited use of IT in the hospital department, lack of integration and stability.
Intermediate	IT systems support most of the hospital's departmental key processes; there is partial integration, and data is beginning to support decision-making.
Advanced	Extensive and consistent system integration, use of reports, indicators, qualitative analyses; managers actively manage processes through IT.
Excellent	Complete system integration, use of AI, predictive analytics, and decision support tools; proactive quality and safety improvement.

The authors intended the model to serve both diagnostic and developmental purposes: to determine the current level of maturity of the department's digitalisation processes and to support management and staff in planning improvement activities and making investment

decisions. It is intended to serve as a self-assessment tool for departments, primarily for internal hospital management purposes.

4.2. The qualitative perspective

The qualitative perspective assesses the extent to which IT systems are utilised in the department's clinical and administrative processes, with particular emphasis on their impact on the quality and safety of patient care, the completeness of documentation, and the ability to make data-driven decisions. This perspective identifies seven criteria that capture various qualitative aspects of the department's operations. To simplify the description in Table 3, three aggregated rating levels have been introduced: low (fragmented and basic levels), medium (intermediate level), and high (advanced and excellent levels).

Table 3.
Criteria for the qualitative perspective

Criterion	**Brief characteristics from the perspective of aggregated levels of the maturity model**
Coordination of clinical processes	• *low:* no IT support, paper documentation, • *medium:* the system supports most processes, including team communication, • *high:* full integration of patient records in real time, using AI, predictive analytics, and remote consultations,
Clinical knowledge management and EDM documentation	• *low:* documentation is mostly paper-based, • *medium:* full EDM management with access to it in the system, • *high:* integration of data from various sources, patient access is online, EDM is AI-supported, and electronic consents for treatments,
Clinical decision support	• *low:* lack of IT tools, decisions based solely on experience and analysis of traditional documents, • *medium:* basic alerts (e.g., drug interactions), treatment recommendations, • *high:* reports integrated with EMR, risk prediction, dynamic treatment suggestions, integration with knowledge bases,
Big Data analysis in clinical and administrative processes	• *low:* traditional analysis tools only, mostly manually collected data, • *medium:* access to reports and quality indicators, basic dashboards, • *high:* regular operational and quality analysis using IT, automatically generated alerts, full use of BI, AI, IoT; predictive analytics and benchmarking,
Adapting the IT infrastructure to the needs of the branch	• *low:* infrastructure not tailored to needs and unstable, staff lack trust in the IT systems used. • *medium:* IT systems operate stably, medical devices are partially integrated with IT systems, and IT support responds to failures. • *high:* regular collaboration with the IT department on expanding the IT infrastructure, flexible and proactive infrastructure, integrated with BI/AI, and the department participates in pilots of new solutions.
The degree of integration of medical devices with hospital systems	• *low:* no integration, data transcribed manually, • *medium:* partial integration of selected devices, • *high:* full automatic integration and analysis of device data, alerts generated based on device data,
Supporting the quality and safety of care	• *low:* no recording of adverse events (potentially harmful) and risk incidents in IT systems, • *medium:* regular use of quality modules in IT systems to analyse and prevent adverse events, responding to security alerts generated by systems, • *high:* real-time analysis of quality indicators, use of BI, predictive analytics, and monitoring the effectiveness of actions.

The qualitative perspective is the foundation of the entire model, as it allows for the assessment of the extent to which IT solutions actually translate into the department's basic tasks, i.e., ensuring the effectiveness of clinical processes, making data-driven therapeutic decisions, and ensuring patient safety.

4.3. Organisational perspective in the digitalisation maturity model of hospital departments

The organisational perspective encompasses aspects of process and resource management that determine the effectiveness of IT use within a department. It addresses compliance with legal regulations and security, employee digital competence, risk management, infrastructure development, and the degree of digitalisation of administrative processes. An assessment from this perspective allows us to understand the extent to which a unit can systematically implement and develop IT in its daily operations. This perspective is briefly summarised in Table 4.

Table 4.
Criteria for the organisational perspective

Criterion	**Brief characteristics from the perspective of aggregated levels of the maturity model**
Compliance management	• *low:* lack of awareness and procedures, lack of training and monitoring; incidents of non-compliance reported sporadically, • *medium:* compliance procedures are in place, and staff are trained in them; the manager monitors their application, and incidents are recorded, • *high:* active participation in a compliance culture, systematic audits, employees report potential risks and contribute to the creation of good practices,
Digital competences of the team	• *low:* lack of IT training, knowledge acquired informally by staff, no IT competency assessment in employee appraisal, • *medium:* available training program and educational materials, initial IT competency assessment, manager gathers information on IT training needs, • *high:* personalised development programs, mentoring, periodic competency assessment, culture of IT knowledge sharing,
IT Operational Risk Management	• *low:* lack of knowledge of security procedures, no IT adverse event log or contingency plans, • *medium:* established procedures for reporting IT adverse events, reporting log, department participates in developing contingency plans, • *high:* active threat monitoring, periodic training and exercises, proactive reporting of potential risks, participation in audits and procedure improvement,
Patient interaction with HIS systems and telemedicine	• *low:* no electronic patient access to any documentation created in the department, communication is primarily paper-based or one-way, • *medium:* some results available online, partial e-registration, teleconsultations conducted sporadically, consents for procedures recorded electronically, • *high:* full patient access to documentation and online communication, systematic teleconsultations, remote monitoring (IoT), active promotion and support for patients in using digital tools,
Managing the development of IT infrastructure and systems	•*low:* lack of reporting of IT infrastructure development needs, lack of participation in IT projects, •*medium:* regular and formal reporting of IT infrastructure development needs, participation of branch staff in consultations and tests, assessment of the impact of IT projects on branch processes, •*high:* close cooperation with the IT department on infrastructure development projects, initiation of innovations, systematic collection of feedback, and implementation of improvements,

Cybersecurity	• *low:* lack of procedures and training, low awareness of threats, lack of incident records, bad habits and practices (e.g., password sharing), • *medium:* adherence to established procedures, basic training within the department (taking into account specifics), incident logging, internal audits, • *high:* proactive identification of risk factors and threats, periodic training, safety culture, participation in simulations, and co-creation of educational materials focused on the specifics of the department,
Digital Administrative Processes (ERP)	• *low:* no ERP systems, processes conducted manually or in spreadsheets, • *medium:* use of selected ERP functions (e.g., requisitions, leave), some electronic processes, basic training, • *high:* full support for ERP processes, real-time reporting, use of data for decision-making and optimization, participation in process improvement,

4.4. Technical perspective

The technical perspective encompasses aspects of the hospital department's IT infrastructure and tools. This perspective allows us to assess the extent to which technical solutions support clinical and administrative processes and whether they enable the department's digitalisation process to progress. Ultimately, the level of technical advancement, described in Table 5, determines the stability, consistency, and security of the department's digitalisation.

Table 5.
Criteria of the technical perspective

Criterion	**Brief characteristics from the perspective of aggregated levels of the maturity model**
Data management and reporting	• *low:* lack of consistent data, manual or scattered reports; management does not use metrics, • *medium:* access to basic reports and analyses; data supports clinical and administrative planning, • *high:* advanced reporting tools used in the department BI, AI, prediction, and real-time reporting,
Interoperability and integration of IT systems	• *low:* the department uses multiple independent systems, and data is transferred manually, • *medium:* systems provide insight into key clinical data from various sources, partially integrated interfaces, • *high:* full integration of IT platforms in real time, data available immediately, integration with external sources (e.g., ZUS, P1),
End-user support	• *low:* lack of formal IT support, problems solved ad hoc, lack of training tailored to the department's needs, • *medium:* helpdesk in place, procedures for reporting and resolving problems, training aligned with the department's identified needs, • *high:* advanced user support portal supported by AI and chatbots, reporting on the quality of department support from IT, personalized training,
Scalability and flexibility	• *low:* outdated IT infrastructure, lack of business continuity plans, IT systems not adapted to mobile devices, • *medium:* modular IT systems, partial scalability, basic BCP and DRP plans, • *high:* flexible infrastructure (e.g., cloud), dynamic scaling, resilience to load increases, automated DRP testing, and resource optimization,

Cont. table 5.

Advanced and ergonomic IT systems	• *low:* limited use of IT systems on the ward, non-intuitive interfaces, lack of automation of routine activities, • *medium:* IT systems supporting most processes on the ward, ergonomic interfaces, partial automation of typical activities, • *high:* intelligent systems with AI and ML, adaptive interfaces, automatic process optimization, systems learning based on user behavior patterns,
Security and data transmission	• *low:* no data encryption at the department or use of outdated methods; basic backup system, • *medium:* encrypted communication channels, two-factor authentication, automatic backups, • *high:* blockchain and SSI solutions, full transparency, intelligent risk detection systems, compliance with ISO/IEC standards,

5. Discussion

The essence of the proposed maturity model is the assessment and improvement of digitalisation processes at the hospital department level. Departments differ in their workflows, patient profiles, information needs, and how they utilise IT systems. Analysis at the organisation-wide level does not capture these differences. It often blurs local barriers, such as differences in staff digital competencies, hardware limitations, specific workflows, or management's differing attitudes toward digitalisation. Drilling down to the department level allows for more precise diagnosis and, consequently, more effective implementation of solutions, for example, customised training, system interface modifications, or optimisation of therapeutic and administrative procedures. From an economic perspective, the proposed maturity model serves as a decision-support tool for capital budgeting in healthcare. By identifying departments with the lowest digital maturity, hospital managers can prioritise investments where the marginal utility of IT adoption is highest, preventing the inefficient "siloed" spending that often plagues public healthcare systems.

The lack of consistent digitalisation across departments creates significant challenges throughout the hospital. Situations in which some departments use electronic ordering systems while others continue to rely on paper or ad hoc processes result in fragmented information flows and organisational chaos. This applies not only to collaboration with diagnostic departments but also with the pharmacy, administration, and other support units. Ensuring consistency in areas critical to patient safety, such as communicating information about drug intolerances, coordinating inter-departmental consultations, and preparing patients for procedures, is particularly important. From a hospital-wide perspective, the lack of integration at the department level results in delays, increased risk of errors, and higher costs. The model's granular approach addresses internal information asymmetries within complex hospital structures. By quantifying maturity at the departmental level, the framework enables a more

precise evaluation of the relationship between digital advancement and operational efficiency (e.g., reductions in length of stay or error rates), which is a key focus in health econometrics.

Involving departments in the testing and implementation of new technologies is also particularly important. On a smaller scale, this reduces risk and costs while increasing the accuracy of solutions, as clinical and administrative staff are best placed to identify areas where information-flow problems occur. Therefore, the model also supports creating a space to discuss digitalisation processes that are not always visible at the hospital management level.

An additional value of the proposed approach is its potential for benchmarking. Comparisons between departments within a single hospital, as well as between similar departments in different facilities, help identify gaps and set priorities for improvement. Benchmarking, in this context, provides a practical tool that supports gradual, continuous improvement by enabling hospitals to compare their performance against models and industry standards. Furthermore, the model facilitates analysis of opportunity costs associated with delayed digitalisation. Inefficient digitalisation at the clinical unit level leads to hidden costs from redundant administrative tasks and suboptimal resource utilisation. Our framework provides a strategic roadmap to mitigate these economic losses.

While the inclusion of advanced technologies such as blockchain, predictive analytics, and AI-supported solutions at high levels of maturity may appear speculative, they serve a dual methodological purpose. First, these criteria are realistic reference points for leading Polish academic and clinical hospital centres, which are digital pioneers and have successfully piloted and implemented cloud computing, BI, and AI tools. Second, incorporating these advanced components ensures the model's longevity and 'future-proofing', allowing it to remain a relevant and forward-looking diagnostic framework as the broader digital transformation of the healthcare sector accelerates over the coming years.

From a theoretical perspective, the proposed model provides a framework for examining the evolution of IT processes at the micro level - i.e., within hospital organisational units. It thus offers a new perspective on assessing digital maturity in the healthcare sector, enabling benchmarking and the design of future models that account for both local specificities and the possibility of cross-organisational comparisons.

6. Conclusions

The maturity model for digitalisation processes in hospital departments presented in this article enables a more detailed and differentiated assessment of digitalisation levels than previous approaches that focus on entire institutions. Previous assessments conducted for external stakeholders (primarily the National Health Fund and the Ministry of Health in Poland) are highly aggregated and therefore less responsive to the needs of individual hospital

managers. From an economic standpoint, the model acts as a framework for evidence-based investment prioritisation. Disaggregating digital maturity at the departmental level enables hospital management to mitigate the risk of misallocated capital and ensures that IT investments are directed to units where they can generate the greatest efficiency gains and improvements in service delivery.

The proposed model, based on three perspectives – qualitative, organisational, and technical – enables the identification of the strengths and weaknesses of the digitalisation process in relation to the realities of clinical, managerial, and technological work. The model's structure also incorporates the practical aspect of self-assessment: each perspective can be assessed in collaboration with relevant stakeholders, for example, the technical perspective with the IT department, the organisational perspective with central administration, and the qualitative perspective with auditors or clinicians. The goal of the model was to create a tool primarily for internal use by hospital management in decision-making. The model provides significant practical value by offering departmental management and staff a self-assessment tool to support improvement planning, investment decision-making, and coordination of activities across hospital units. The ability to compare results both between departments within a single facility and between hospitals is also critical. However, this isn't about competition; it's about sharing experiences and identifying best practices to support standardisation processes and contribute to the gradual improvement of healthcare IT systems. An inherent limitation of any model based on self-assessment is the risk of subjective bias or overestimation by departmental managers, particularly in sensitive areas such as compliance culture, cybersecurity practices, and operational risk management. However, within this model's framework, this risk is substantially mitigated by two factors. First, the evaluation is designed as a collaborative internal process involving multiple stakeholders within each ward, creating a system of peer accountability where assessments are transparent to colleagues. Second, since the model is explicitly designed as an internal diagnostic tool for self-improvement rather than an external ranking or punitive auditing instrument, departments have a strong practical incentive to provide accurate data to identify real operational bottlenecks and resource needs.

From a theoretical perspective, the model builds on research on healthcare maturity models, shifting the focus from the entire institution to the departmental level. This approach better captures the complexity of hospital digitalisation processes, the diversity of needs across individual units, and the importance of organisational and cultural factors in the adoption of digital technologies. Furthermore, the model suggests directions for potential process standardisation within similar departments, which can also provide essential inspiration for IT system manufacturers, who often focus on hospital-wide aspects while ignoring the specifics of clinical units. Moreover, the model helps reduce information asymmetry between healthcare providers and IT vendors. By defining clear maturity benchmarks, hospitals can more precisely specify their technological needs, potentially leading to more competitive procurement processes and reduced long-term costs of system ownership and integration. In this context,

identifying best practices for collaborating with patients and their families in similar departments, such as geriatrics, paediatrics, or those caring for chronically ill patients, is particularly important. It should be emphasised that work to date has primarily focused on expert validation.

Future research will focus on the extensive empirical testing of the proposed model across a wider network of hospital departments, both nationally and internationally. A key objective of subsequent studies is to investigate how specific maturity scores correlate with measurable clinical and operational outcomes, such as medical documentation completeness, adverse event reduction, patient waiting times, length of stay (LOS), and cost per patient day. Following the full validation and academic evaluation phase, the model is intended to be made publicly and openly accessible. This open-access approach encourages hospitals to adopt it and establishes a collaborative data-collection framework that will enable longitudinal analysis of the effects of digitalisation on healthcare efficiency and patient safety.

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CONSUMER ATTITUDES TOWARDS CSR VERSUS THEIR PURCHASING CHOICES IN THE CONTEXT OF SUSTAINABLE DEVELOPOMENT

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Purpose: The purpose of this paper is to examine relationships between consumer attitudes towards corporate social responsibility (CSR) and their real purchasing choices in the context of sustainable development. The paper focuses on identifying factors that affect consumer decisions and assessing to what extent CSR activities affect market behaviors of consumers.
Methodology: The basis hereof is the review of the source books, including domestic and foreign scientific publications on CSR, sustainable development and consumer behaviors. As part of the author's own research conducted at the end of June and at the beginning of July 2025, survey respondents were selected on a randomized basis constituting a research sample of 300 people. Then a statistical analysis was performed with the use of a two-factor variance analysis (ANOVA) and post-hoc Tukey tests, against the level of statistical significance of 0.05. Tukey's tests allowed a detailed analysis of the average by identifying homogenous statistical groups. Also confidence intervals were calculated for researched qualities in regard of the average against the confidence level of 0.95. The calculations were made using Statistica 13.1 (StatSoft Inc., USA).
Findings: The research shows that consumer attitudes towards CSR and sustainable development have been increasingly positive; however, in practice their purchasing decisions are still, to a large degree, determined by products' price, quality and accessibility. There is a significant gap between consumers' attitudes and their behaviors. The importance of CSR in purchasing decisions has, however, grown in groups of younger consumers and among people with higher environmental awareness.
Practical implications: Based on research results, companies should not only implement CSR activities but should also ensure reliable and transparent communication of such activities. Building consumer trust requires authenticity of activities and avoiding greenwashing. The companies can make their CSR strategies more effective by educating consumers and integrating social and environmental activities with their basic business strategy.
Originality: This paper incorporates three research areas: sustainable development, CSR and consumer behaviors, showing their mutual relationships in the context of modern-day purchasing decisions. Special attention was given to the phenomenon of the attitude- behavior gap and its importance to the effectiveness of CSR activities on the market.
Keywords: Corporate social responsibility, sustainable development, consumer behaviors, purchasing decisions.
Category of the paper: research paper.

1. Introduction

The modern market has been more and more responsive to ideas of sustainable development and growing social awareness of consumers. In the face of climatic changes, degradation of the natural environment and growing expectations with regard to companies, the concept of corporate social responsibility has become a key element of corporate strategies. Corporations have been more often engaged in activities involving environment protection, ethical management, social responsibility or transparency of their business, trying to develop their positive image and earn customers' trust.

Products' price and quality are no longer the only factors considered by consumers; instead, consumers have been paying increasing attention to brand values. Nowadays purchasing decisions frequently reflect consumer attitudes, beliefs and interest in social or environmental issues. Responsible consumption has become an important element behind the implementation of the idea of sustainable development and consumers have been increasingly expecting companies to act ethically and protect the environment.

Currently the relationship between CSR activities and consumers' purchasing decisions is an important area of research and market analyses. On the one hand, declarations of social responsibility may help increase customer loyalty and competitive advantage of companies, on the other hand, however, doubts arise as to the authenticity of such activities and the phenomenon of greenwashing. Hence, it is important to understand a degree to which consumer attitudes towards CSR indeed have an effect on their purchasing behaviors.

The purpose of this paper is to examine relationships between consumer attitudes towards corporate social responsibility (CSR) and their real purchasing choices in the context of sustainable development. The paper focuses on identifying factors that affect consumer decisions and assessing an extent to which CSR activities affect market behaviors of consumers.

2. Sustainable growth in theory

Sustainable growth is one of the most important and most influential concepts of the modern economy, politics and social sciences, and it aims at shaping growth processes in such way that needs of present generations can be met without compromising the ability to meet those of the future ones. A classical definition of that concept was formulated in the Report of the World Commission on Environment and Development (the Brundtland Report) which specified that sustainable development involves balancing economic, social and environmental needs in a long-term perspective (WCED, 1987). Source literature emphasizes that the idea was developed in view of growing awareness of adverse impact of the consequences of

industrialization such as degradation of natural environment, running out of resources or increasing social inequalities.

From a theoretical perspective the idea of sustainable development is based on three fundamental pillars: economic, social and environmental. The economic pillar refers to the necessity of ensuring stable economic growth that does not result in excessive exploitation of natural resources and enables long-term growth of the economy. The social pillar involves issues such as social justice, reduction of inequalities, improving the quality of life and ensuring access to basic public services, whereas the environmental pillar is focused on the protection of ecosystems, emission control, rational management of natural resources and preventing climate change. The integration of those three pillars is the basis of the concept called triple bottom line proposed by J. Elkington (1997) who stressed the necessity of taking into account economic, social and environmental performance in business activities (Elkington, 1997).

The idea of sustainable development is nowadays implemented, to a large extent, by way of activities of enterprises that have increasingly incorporated environmental and social aspects into their business strategies. In practice that means aiming to operate a business in such way that allows to achieve economic benefits and at the same time reduce negative impact on the environment as well as taking into account social needs of stakeholders (Zuzek, 2014). One of key tools allowing to implement that concept is corporate social responsibility (CSR) understood as voluntarily taking into account, by businesses, social, environmental and ethical interests in the management process and in relations with their stakeholders (Carroll, 1991).

The importance of sustainable development, however, goes beyond the area of corporate business and also involves changes in attitudes and behaviors of consumers. Increasingly often modern consumers have been declaring their interest in products and services manufactured in a socially and environmentally responsible manner. The above contributes to the development of a phenomenon described as ethical consumption whereby purchasing decisions are taken by consumers who take into account the impact of a product on the natural environment as well as social conditions of its manufacturing process (Peattie and Crane, 2005). Consumers can choose ecological, certified products (e.g. fair trade), local ones or those manufactured by companies that have been implementing a CSR policy.

However, the empirical research shows that despite growing social and environmental awareness, there is a clear discrepancy between the attitudes declared by consumers and their actual purchasing behaviors. That phenomenon is described as an attitude–behavior gap and is one of key challenges in the analysis of sustainable consumption (Carrington, Neville, Whitwell, 2010). Major reasons behind that phenomenon include, among other things, a higher price of ecological products, limited access to information on their environmental impact, distrust in statements made by companies and strong consumer habits.

From a global perspective sustainable development is a response to contemporary civilization challenges such as climate changes, loss of biodiversity, degradation of a natural environment as well as growing social inequalities. In this context international initiatives are

particularly important, including the 2030 Agenda of the United Nations that specifies 17 Sustainable Development Goals (SDGs) which constitute a comprehensive plan of action to improve the quality of life of people and the protection of the planet (United Nations, 2015). The implementation of those goals requires collaboration between governments, non-governmental organizations and a civic society.

3. Corporate social responsibility in the theory of economy

A modern approach to Corporate Social Responsibility treats an enterprise as an integral part of a social environment which both influences and at the same time is subject to its influence.

Carroll's model shows that CSR encompasses four areas of responsibility: economic, legal, ethical and philanthropic all of which form a comprehensive approach to the responsible performance of economic activities. In practice that means, among other things, reducing the emission of hothouse gases, implementing ecological technologies, improving working conditions in supply chains and increasing the transparency of business operations (Kotler, Lee, 2005). Economic responsibility refers to companies' basic task, that is, generating profits. Legal responsibility means the necessity of compliance with applicable laws. Ethical responsibility involves social values and standards that are not always regulated by laws, however, they are expected by the society. The last area, the philanthropic one, refers to actions voluntarily taken for the society, such as donations or charity (Carroll, 1991).

A current approach to CSR has been significantly expanded upon the development of the concept of sustainable development and CSR is frequently treated as a practical dimension of the implementation of the principles of CSR in the operations of a business. The implementation of the principles of CSR and sustainable development may contribute to the growth of the attractiveness of enterprises and to the development of their competitive advantage. Environmental initiatives and taking into account social aspects in business operations contribute not only to improving a company's corporate image but also to increasing the development of stakeholders' trust and fostering long-term relationships with customers. At the same time the implementation of the principles of sustainable development requires that companies have adequate knowledge, become engaged in and bear extra expenses related to the implementation of responsible practices" (Zuzek, 2012).

A stakeholder theory developed by R. Edward Freeman is a key element of CSR, according to which a company should take into account the interests of all groups that influence or are influenced by its operations such as employees, customers, suppliers, local communities and investors (Freeman, 1984). From this perspective the company's success is not measured solely

in terms of its financial profits but also in terms of the quality of its relations with social environment.

In practice CSR offers a broad array of activities such as implementing a policy of ethical management, ensuring labor conditions, reducing adverse impact on natural environment, supporting local communities and transparency in communication with stakeholders. Also the role of the activities related to the disclosure of non-financial information has been growing as such kind of disclosure allows to assess the enterprise's impact on the environment and society. In the European Union the disclosure of non-financial reporting was introduced pursuant to Directive 2014/95/UE pursuant to which large public interest entities are obligated to disclose information related to, among other things, environmental and social matters as well as human rights.

Benefits that stem from the implementation of CSR are multipronged. From the perspective of an entity, its CRS activities may help improve its corporate image, increase customer loyalty and employee engagement. Socially responsible businesses are frequently perceived as more reliable and stable which, in turn, may facilitate their access to capital and reduce investment risk (Porter, Kramer, 2006). On the other hand, from the perspective of the society, CSR contributes to improving the quality of life, protecting the environment and strengthening social bonds.

However, CSR is not beyond criticism. Some researchers have noted that those activities can be used as a marketing tool only, i.e. as so-called greenwashing which is a deceptive practice of making an environmentally-friendly policy aimed at improving the company's image more environmentally friendly than it actually is without any real changes in its functioning. Critics have also emphasized that the company's basic purpose should be generating profits for its owners rather than implementing social goals that may lead to diluting management responsibility (Friedman, 1970).

Despite those controversies CSR has become an increasingly important element of business strategies all over the world. Due to globalization, developing information technologies and growing consumer awareness, companies have been under growing pressure of transparency and responsible action. Especially younger generations of consumers pay attention to ethical aspects of business operations which, in turn, affects purchasing decisions and brand loyalty.

4. CSR versus market behaviors of consumers

A modern market economy has been functioning in the conditions of growing social and environmental pressure which leads to redefining the role of enterprises and their responsibility towards the environment. As globalization increases and information technologies rapidly develop, consumers experience greater access to information about the activities of businesses

which has significant impact on the awareness and expectations from business. In consequence, the concept of corporate social responsibility has become one of vital elements of corporate strategies and an important factor that impacts consumer behaviors (figure 1).

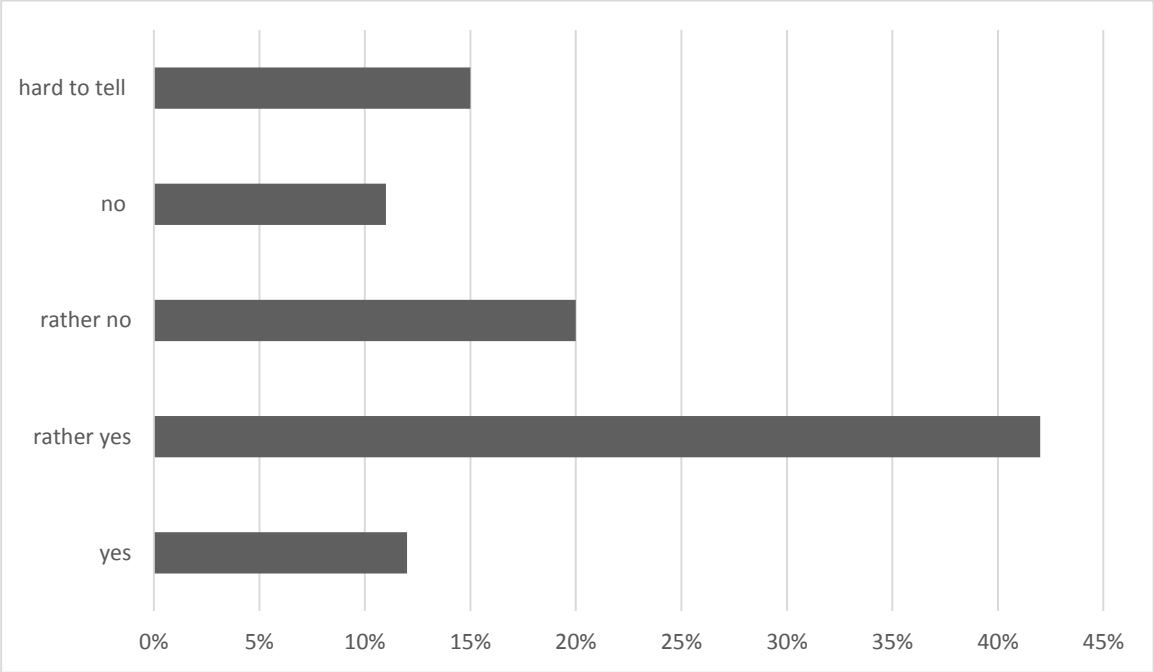

Figure 1. Consumers' readiness to spend more money on products of socially responsible companies. Source: the author's own research.

Sustainable development in the context of consumption necessitates informed purchasing decisions that take into account the impact of products and services on the natural environment and the society. Through their market choices consumers have been playing a crucial role in the process of promoting sustainable practices and exerting pressure on the companies in the area of implementing CSR activities.

The analysis of consumer attitudes towards CSR activities requires taking into account their multipronged nature. A classical approach is based on three components of consumer attitudes: cognitive, emotional and behavioral. The cognitive component refers to the level of consumer knowledge of CSR activities, whereas the emotional component encompasses their attitude to those activities. The behavioral component, in turn, refers to the actual activities of consumers such as purchasing choices or brand loyalty.

The empirical research shows (figure 2) that consumers have been paying greater attention to CSR activities of businesses. The above, in particular, refers to younger generations such as generation Z which is highly sensitive to social and environmental issues and declares that it is ready to support socially responsible companies (Pacut, 2024). At the same time, however, the results of the research show that consumer attitudes vary materially depending on demographic factors and a system of values.

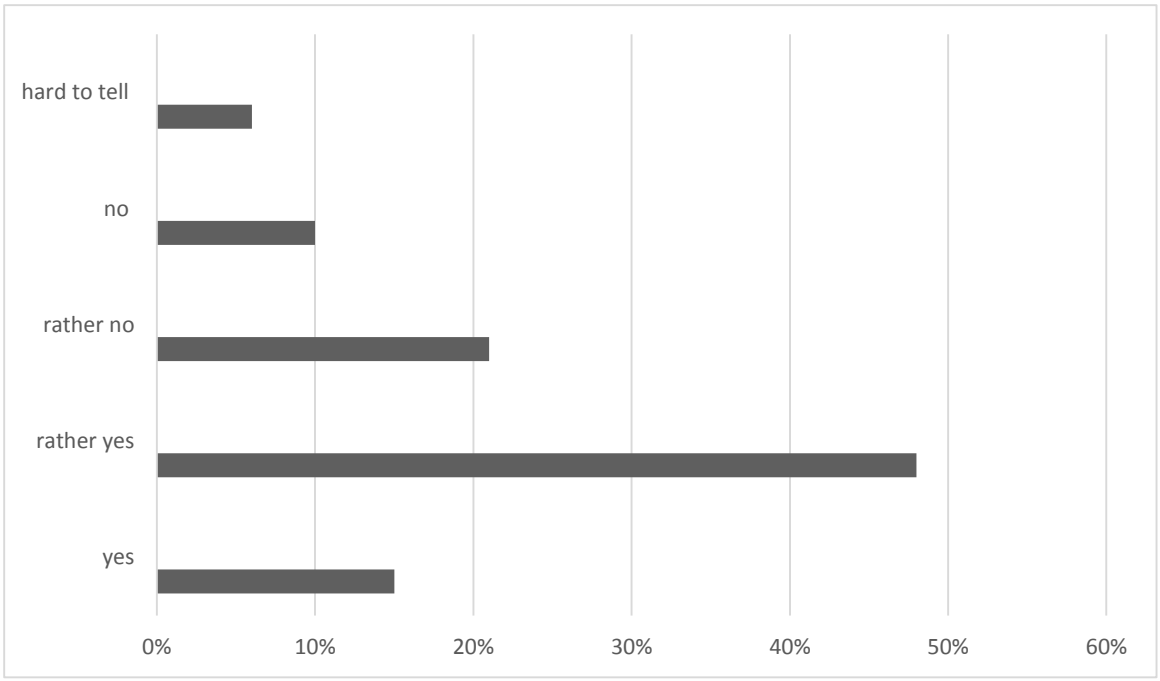

Figure 2. The importance of engagement of enterprises in socially responsible actions.
Source: the author's own research.

Subject literature emphasizes that purchasing decisions of consumers are determined by many factors, with, among other things, economic conditions being of key importance. The price of a product remains to be the one of the most important choice criteria which, in turn, limits the importance of CSR in a decision-making process. Sustainably manufactured products frequently cost more which can be attributed to expenses related to the implementation of responsible practices.

Another important factor that impacts behaviors of consumers is their knowledge and awareness. The research shows that consumers are often familiar with the concept of CSR, however, not always do they have sufficient information regarding the CSR activities taken by a specific enterprise which makes it more difficult to take informed purchasing decisions. Thus, the transparency and reliability of the CSR communication play a crucial role in the process of shaping consumer attitudes.

The so-called attitude-behavior gap is an important issue in the process of the analysis of the relationship between the attitudes and behaviors of consumers. It involves a discrepancy between values declared by the consumers and their actual actions. The research conducted by other researchers confirms the thesis that consumers frequently declare their support for CSR activities, however, in practice making purchasing decisions they are mostly guided by the price, quality of and access to the product. Similar conclusions can be drawn from the experimental research which shows that although CSR has positive impact on purchasing intentions, however, in the wake of economic factors, its importance decreases (Zaborek, Kurzak-Mabrouk, 2025).

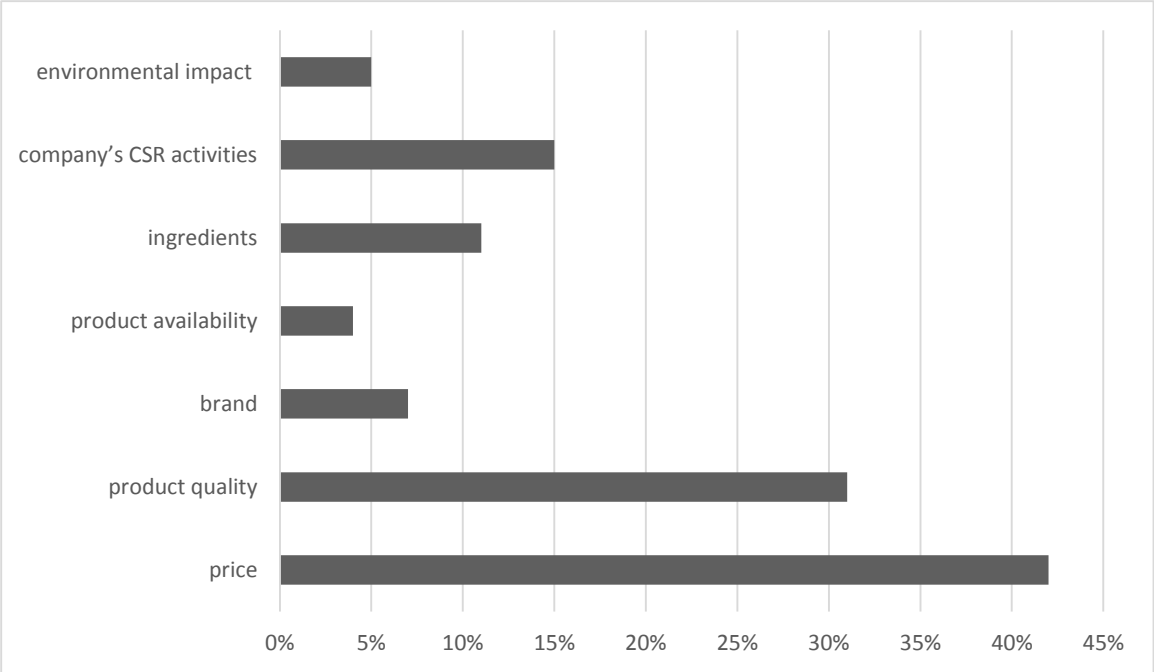

Figure 3. Determinants of consumers' purchasing decisions.

Source: the author's own research (more than one answer could be chosen).

Social and cultural factors also play an important role in the process of shaping consumer attitudes towards CSR. Social standards, cultural values and the influence of reference groups may strengthen or weaken one's tendency to take decisions in line with sustainable development principles. In societies where environmental awareness is high, consumers more frequently tend to choose environmentally friendly products which is confirmed by the research conducted on the Polish market (Maciejewski et al., 2021).

Also psychological factors such as values, beliefs and lifestyle of consumers are important in the process. The persons who identify themselves with pro-environmental values are more likely to take purchasing decisions in line with CSR. However, even among the members of this group a discrepancy can be seen between statements and actions, which, among other things, results from cognitive limitations and the impact of consumer habits.

CSR also plays an important role in corporate marketing strategies. Socially responsible activities may contribute to building a positive brand image and increasing customer loyalty. The subject literature stresses that the efficiency of CSR activities depends on whether they are authentic and in line with the values represented by the consumers. Where there is a discrepancy between the statements and the actual actions, the enterprises face the risk of losing the consumers' trust.

In the context of the Polish market, the economic transformations that occurred after 1989 are especially important. Political transformation helped develop the market and boost competition which, in turn, facilitated the development of conditions favorable to the growth of CSR. Those changes also influenced the development of consumer attitudes as they have

gradually started to pay attention to the issues of quality, safety and corporate social responsibility (Śmigielska, Oczkowska, 2027).

In recent years the importance of the activities related to the protection of the environment has been growing, too. The research shows that CSR initiatives related to ecology have significantly impacted purchasing decisions of consumers, especially younger and more educated ones (Sawicka, Marcinkowska, 2022). However that impact is diverse and depends on many factors such as an individual's income, product availability or knowledge. Social corporate responsibility may be an important element of building a competitive advantage of businesses. The research shows that consumers are eager to reward socially responsible companies by choosing their products and showing greater brand loyalty. At the same time, however, CSR is rarely the only factor determining the purchase – its importance is usually complementary to other factors such as the product price or quality.

Another important element supporting the development of sustainable consumption is education. Growing consumer awareness of the impact of purchasing decisions on the environment and society may contribute to reducing a gap between statements and actions. Education should encompass both the actions of public institutions as well as initiatives taken by enterprises and non-governmental organizations.

5. Summary

Sustainable development and corporate social responsibility play an increasing role in the modern economy and corporate operations. Those concepts are based on the harmonious combination of economic, social and environmental goals so that economic growth does not take place at the expense of the society and the natural environment. CSR is the practical effect of the implementation of sustainable development and encompasses the activities of the enterprises related to, inter alia, environment protection, business ethics, taking care of employees and supporting local communities.

As social and environmental awareness is growing, consumers pay increasing attention to the responsibility of companies and the impact of their operations on the environment. CSR may affect purchasing decisions, help build a positive image of brands and increase customer loyalty. They are very important to younger generations of consumers who are more sensitive to environmental and social issues.

At the same time the analysis of the behaviors of consumers shows that despite their declared support for sustainable consumption, in practice the most important factors that determine purchasing decisions are the price, quality and access to products. The above shows that there is a gap between consumer attitudes and the actual behaviors of consumers.

The importance of CSR in the purchasing process also depends on the level of the knowledge of consumers, credibility of corporate communication as well as social and cultural factors.

CSR's and sustainable development's growing importance shows that the enterprises are increasingly more obligated to do their business in a responsible and transparent manner. In the future further growth of environmental education and growth of social awareness may contribute to increasing the importance of responsible consumption and to the greater impact of CSR activities on the market behaviors of consumers.

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