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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: sustainability; economics; marketing; finances; human resource management; risk management; Industry 4.0; ESG; small and medium enterprises; digital transformation; logistics; smart city; quality of life; virtual reality; leadership; e-commerce; quality management; public management; consumer behavior and artificial intelligence in management.

Radosław Wolniak

BEYOND MINING: IDENTIFYING KEY SECTORS FOR SUSTAINABLE ECONOMIC GROWTH IN MONGOLIA

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Purpose: This paper aims to identify the key sectors and structural features of the Mongolian economy by analyzing intersectoral linkages derived from input–output (IO) tables. We further examine how these linkages and the overall production structure have evolved over time to reveal broader trends in economic transformation.

Design/methodology/approach: We employed demand-driven IO model for analyzing economic structures using national IO tables that published from 2010 to 2019. The data obtained from the National Statistical Office of Mongolia (NSOM) and we focused on multipliers, type I multipliers.

Findings: Our analysis shows that Mongolia's core drivers of domestic production linkages are the manufacturing (C) and electricity and heat supply (D) sectors, which exhibit the strongest output and GVA Type I multipliers. In contrast, public service sectors (O, P, and Q) and the export-oriented mining sector (B) generate limited domestic spillovers despite mining's large GDP contribution. Structural changes between 2010 and 2019 further indicate a growing divergence between industrial sectors that drive production and service sectors—such as real estate (L) and education (P)—that generate the largest wage, employment, and value-added effects.

Practical implications: The identification of processing industries, electricity supply, and construction as Mongolia's core multiplier-intensive sectors provides a practical basis for targeting investment, industrial diversification, and productivity-enhancing policies toward areas with the strongest economic spillover potential.

Social implications: The weak multipliers observed in public services and primary sectors imply limited diffusion of income and employment benefits across society, underscoring the need for policies that strengthen social-sector linkages to support more inclusive and equitable development.

Originality/value: Unlike previous Mongolian IO studies, this paper offers multi-multiplier, decade-long analysis of Mongolia's economic structure using consistent national IO tables, going beyond earlier studies that relied on a single year or sector-specific assessments. The study provides new empirical insights into Mongolia's key sectors and interindustry linkages, offering practical value for economic planners and researchers working on structural transformation in resource-dependent economies.

Keywords: Input–Output models, production, Empirical Studies of Economic Growth, Industrial Structure.

Category of the paper: Empirical research.

1. Introduction

Mongolia is a landlocked country in East Asian country bordered by China and Russia. The country occupies 1.57 million km² (Batima et al., 2005) and has a population of approximately 3.5 million (National Statistical Office of Mongolia, 2023) which gives it the second-to-last position in terms of population density in the world (after Greenland). Until 1989, Mongolia depended on the former USSR for imports and financial aid. Imports accounted for 58% of its GDP, 80% of which came from the USSR. The country's GDP growth rate was 6.1% and 5.7% in the 1970s and 1980s, respectively. From 1940, Mongolia shifted toward a more modern and industrial society, with industry contributing 33% of the national income by 1989, up from 7% in 1940. Agriculture, including animal husbandry, decreased from 76% to 16% during the same period (Aassve, Altankhuyag, 2002). Mongolia has been undergoing dramatic political reforms since 1990 following the collapse of the former Soviet Union. Since the early 1990s, Mongolia's annual GDP growth rate has exhibited volatility, with the rate ranging from a contraction of 20% to an expansion of 17%. This substantial fluctuation is noteworthy globally, potentially representing one of the widest ranges observed internationally.

Since the late 1990s, the Mongolian market has strongly correlated with the fate of Mongolian mining deposits, which are of worldwide interest. Batchuluun & Lin (2010, p. 1) mention that "if these deposits were exploited, the Mongolian capital market would boom and thus strongly affect the whole economic situation". However, Mongolia's natural-resource endowment has driven dynamic yet highly volatile economic growth. Like most economies, GDP declined during the pandemic year but also declined in 2009 (financial crisis) and 2016. The volatility of Mongolian economic growth is related to its reliance on mineral exports. It is vulnerable to global commodity price fluctuations and economic policies in China, its principal trading partner. According to World Bank data, Mongolia is the third country in the world (after Kosovo and Botswana) with the highest share of energy produced from coal, equal to 86.6% in 2022 (for comparison, Norway has the lowest share of coal energy, equal to 0.1%) (World Bank Open Data, 2023).

Since the mid-2000s, the mining and quarrying industry has been the backbone of Mongolia's economy, contributing 1/3 of GDP in 2024 (National Statistical Office of Mongolia, 2024a). Mining sector generates over 80% of export revenues. This dependence makes the country vulnerable to price fluctuations in global markets and the lack of direct sea access limits export options and increases logistics costs. Addressing these supply chain risks requires diversifying the economy, investing in infrastructure, and strengthening regulatory

frameworks to ensure sustainable and resilient economic growth. Dominant role of mining sector exposes the country to the stagnation in other sectors such as agriculture and services. The growing role of the mining industry has been accompanied by a decline in agriculture – historically the most important sector in the Mongolian economy. Within the last three decades, agriculture's share has fallen from 38% (in 1996) to 7% in 2024 (National Statistical Office of Mongolia, 2024b). The pivotal role of mining stops Mongolia's transformation from an agriculture-based to a service-based economy, as the share of services decreases since the rise of mining. The below chart shows the strict negative correlation between primary sector and service sector in Mongolia (correlation coefficient: -0.97).

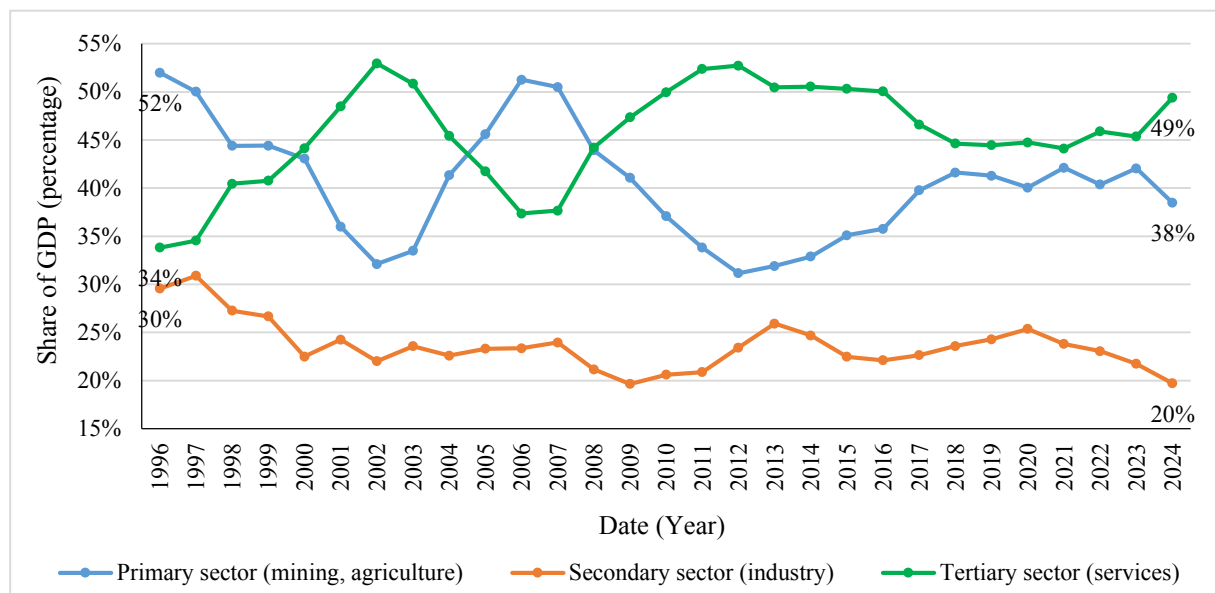


Figure 1. GDP share in three sectors in Mongolia.

Source: Own study based on data from NSOM (2024b).

As the primary sector (mining and agriculture) significantly impact the Mongolian economy, but it is unclear whether they are key sectors in the economy. To clarify this, key sectors need to be defined. Each economy comprises numerous interindustry linkages, with each sector having varying degrees of connections (weak or strong) to others. The size of a sector is not significant in this context, however. A key sector is defined as ‘a sector which, on the one hand, is largely dependent on other industries—utilizing their products in its production process—and on the other hand, has its output used as an intermediate product in other sectors’ production processes’ (Umed, 2004, p. 2). Furthermore, identifying key sectors and understanding the economy’s structure are crucial for policymakers to formulate effective strategies for economic development. Here, the economy’s structure is the composition of macroeconomic aggregates and the intricate interactions among them (Alatrisme-Contreras, 2015).

In this paper, we aim to find key sectors and economic structures in Mongolia, as well as the linkages between sectors and trends in the economy’s structure, that emerge from analyzing input–output (IO) tables.

Our analysis of the IO literature indicates a gap and a need for studies that offer a comprehensive analysis of direct and indirect supply–demand interdependencies among economic sectors in Mongolia.

2. Methodology

The IO tables offer detailed insights into the interactions between domestic suppliers and users of locally produced raw materials, industrial components, and services. These inter-industry transactions offer valuable information about the structure of production processes and the intricacy of the supply chains that support economic activity (Lenzen et al., 2012; Leontief, 1936; Suh, 2010; Wixted et al., 2006). Mongolian Statistical Office offers 20x20 input-output tables according to the International Standard Industrial Classification of All Economic Activities (ISIC) rev. 4 classification – see Table 1.

Table 1.
*Sections according to the ISIC Vol. 4 classification**

	Sectors		Sectors
A	Agriculture, forestry and fishing	K	Financial and insurance activities
B	Mining and quarrying	L	Real estate activities
C	Processing industries (manufacturing)	M	Professional, scientific and technical activities
D	Electricity, gas, steam, air conditioning supply	N	Administrative and support service activities
E	Water supply; sewerage, waste management and remediation activities	O	Public administration and defence; compulsory social insurance
F	Construction	P	Education services
G	Wholesale and retail trade; repair of motor vehicles and motorcycles	Q	Human health and social work activities
H	Transportation and storage	R	Arts, entertainment and recreation
I	Accommodation and food service activities	S	Other service activities
J	Information and communication	T	Activities of households as employers

*We use “sectors” and “sections” interchangeably for clarity and simplicity of description. However, we always mean sections in the sense of the ISIC classification. This classification follows a coherent and consistent structure for classifying economic activities based on a set of internationally agreed-upon concepts, definitions, principles, and classification rules.

Source: Adopted from International Standard Industrial Classification of all Economic Activities by UN, 2008, Vol. 4, p. 43.

Our selection of the IO model for this analysis is based primarily on data availability. The Mongolian National Statistical Office (NSOM) is the principal data source for this study, with the most recent table available (at the end of 2025) for 2019 (20 x 20 IO table). The NSOM published IO tables annually for 2010–2019, although many countries publish IO tables every five years. Unfortunately, NSOM will not publish the input-output table for 2020 due to

COVID-19 and other methodological issues (as they inform the authors via email). NSOM is working on producing IOT for 2024, which will be published in 2026 or later.

In this study, we use the demand-driven IO model in which the total output of a sector is expressed as a function of the demand for the various commodities produced in the economy:

$$\mathbf{X} = \mathbf{L}\mathbf{Y}, \quad (1)$$

where:

$\mathbf{X}$ is 20x1 vector of total production (total output) in a given section (see Table 1),

$\mathbf{Y}$ – is 20x1 vector of final demand in a given section,

$\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ is an 20×20 Leontief matrix with elements l_{ij} ,

$\mathbf{A}$ is a 19x19 matrix of input (technical) coefficients as the ratio of input supplied by sector i and purchased by sector j over the output of sector j : $a_{ij} = x_{ij}/X_j$.

There are possibility of calculating multipliers which quantify the total effects of an increase in one unit of final demand in each section on output, income, employment, and value-added in the whole economy in IO analysis (Miller, Blair, 2009). Calculations of multipliers rely on Leontief matrix $\mathbf{L}$ and proportion of employment, wages and GVA in total production – as shown in table 2.

Table 2.

The formulae for multipliers

Output Multiplier	Income Multiplier	Labor Multiplier	Value-Added Multiplier
$j = \sum_{i=1}^{20} l_{ij}$ Designation as in formula (1)	$W_j = \sum_{i=1}^{20} w_i \cdot l_{ij}$ Where w_i is the ratio between wage and total input	$L_j = \sum_{i=1}^{20} l_i \cdot l_{ij}$ Where l_i is the ratio between labour and total output	$V_j = \sum_{i=1}^{20} v_i \cdot l_{ij}$ Where v_i is the ratio between value added and total output

Source: Adopted from Handbook of Input-Output table compilation and analysis, by United Nations, 1999, p. 264.

3. Results

In below table there are 4 types of multipliers which shows how the 1 unit growth in final demand in given section increase output (Table 3), income (Table 4), employment/labour (Table 5), and gross value-added (Table 6) in the whole economy.

Table 3.
Output multiplier

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Annual growth
A	1.30	1.34	1.28	1.29	1.31	1.30	1.38	1.32	1.32	1.32	0.3%
B	1.41	1.29	1.36	1.40	1.49	1.44	1.41	1.37	1.36	1.40	0.2%
C	1.78	1.71	1.70	1.65	1.67	1.77	1.74	1.72	1.77	1.78	0.3%
D	2.28	2.16	2.17	2.32	1.65	1.79	1.86	1.86	1.93	1.95	-2.1%
E	2.11	2.06	1.97	2.04	1.79	1.57	1.61	1.66	1.62	1.59	-3.5%
F	1.73	1.61	1.62	1.54	1.64	1.64	1.67	1.54	1.56	1.64	-0.4%
G	1.42	1.25	1.30	1.32	1.36	1.34	1.34	1.32	1.36	1.34	0.1%
H	1.30	1.31	1.43	1.41	1.39	1.29	1.31	1.32	1.29	1.31	-0.4%
I	1.76	1.77	1.63	1.65	1.64	1.67	1.66	1.67	1.74	1.72	-0.1%
J	1.44	1.45	1.43	1.34	1.33	1.38	1.38	1.51	1.48	1.47	0.4%
K	1.35	1.34	1.23	1.26	1.20	1.34	1.36	1.32	1.28	1.34	0.2%
L	1.29	1.11	1.25	1.27	1.29	1.28	1.26	1.24	1.25	1.31	0.5%
M	1.53	1.60	1.34	1.56	1.37	1.42	1.39	1.41	1.47	1.43	-0.8%
N	1.58	1.73	1.51	1.79	1.69	1.62	1.61	1.62	1.65	1.70	0.2%
O	1.37	1.50	1.39	1.53	1.29	1.21	1.19	1.18	1.18	1.18	-2.8%
P	1.40	1.40	1.32	1.38	1.26	1.32	1.31	1.33	1.34	1.31	-0.6%
Q	1.45	1.45	1.33	1.30	1.28	1.28	1.27	1.27	1.28	1.31	-1.2%
R	1.61	1.71	1.33	1.53	1.44	1.41	1.42	1.36	1.37	1.39	-1.8%
S	1.47	1.77	1.36	1.52	1.73	1.62	1.58	1.61	1.64	1.66	0.9%
CoV*	17.5%	17.7%	17.0%	18.0%	12.9%	12.3%	12.8%	13.1%	14.0%	14.0%	

*Coefficient of variation.

Source: Our own calculation.

The output multiplier indicates how a one-unit increase in final demand in a given sector affects total output across the entire economy.

The most significant values are for industry Sections (C and D) and some service Sections (I, N). The output multiplier for Section D has the highest value at 1.94 in 2019 indicating that a 1 unit (1 MNT - Mongolian currency, the tugrik) increase in final demand for this sector results in a 1.94 unit (MNT) increase in output across all sectors; the lowest level of participation in global production in terms of meeting final demand is Section O. The last column shows that, in most sections, the output multipliers are stable over time; a significant downward trend appears in the D, C, and O sectors. The falling trend indicates that less and less production is required to meet the final demand in a given sector. This suggests the more economical uses of intermediate goods in production.

Table 4.
Income multiplier

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Annual growth
A	0.05	0.12	0.10	0.09	0.10	0.10	0.11	0.10	0.10	0.10	2.4%
B	0.11	0.14	0.19	0.18	0.16	0.16	0.16	0.13	0.13	0.13	-0.6%
C	0.11	0.12	0.13	0.13	0.13	0.14	0.15	0.14	0.14	0.14	2.5%
D	0.30	0.35	0.36	0.40	0.34	0.31	0.32	0.30	0.27	0.25	-2.9%
E	0.38	0.43	0.41	0.41	0.37	0.40	0.42	0.41	0.39	0.40	-0.2%
F	0.16	0.12	0.11	0.12	0.16	0.18	0.20	0.20	0.20	0.20	6.6%
G	0.18	0.13	0.18	0.21	0.22	0.22	0.27	0.25	0.23	0.24	5.3%
H	0.14	0.16	0.18	0.18	0.20	0.20	0.21	0.21	0.20	0.20	3.5%
I	0.22	0.24	0.23	0.27	0.26	0.28	0.29	0.27	0.25	0.25	1.6%
J	0.20	0.21	0.21	0.22	0.21	0.24	0.22	0.23	0.22	0.21	0.7%

Cont. table 4.

K	0.31	0.27	0.27	0.21	0.24	0.32	0.32	0.27	0.28	0.26	0.2%
L	0.04	0.03	0.04	0.04	0.05	0.06	0.06	0.06	0.06	0.07	8.1%
M	0.38	0.39	0.38	0.27	0.28	0.35	0.39	0.38	0.33	0.32	-1.0%
N	0.32	0.26	0.25	0.21	0.27	0.32	0.34	0.31	0.29	0.29	1.6%
O	0.49	0.48	0.51	0.55	0.53	0.46	0.41	0.41	0.40	0.39	-3.3%
P	0.62	0.62	0.65	0.65	0.65	0.66	0.66	0.65	0.64	0.64	0.3%
Q	0.51	0.53	0.55	0.55	0.56	0.56	0.51	0.47	0.47	0.46	-1.6%
R	0.51	0.55	0.51	0.54	0.54	0.53	0.48	0.49	0.48	0.48	-1.2%
S	0.34	0.35	0.21	0.24	0.30	0.34	0.34	0.35	0.32	0.32	1.7%
CoV*	59.4%	59.7%	59.3%	61.2%	57.4%	53.0%	48.3%	50.3%	50.9%	51.1%	

*Coefficient of variation.

Source: Our own calculation.

The highest income multiplier for Section P (education) informs us that a 1 unit increase in final demand in 2019 leads to a 0.64 increase in wages across all the sectors. At the same time, growth in demand for Section L (real estate) needs nearly 10 times less in terms of increases in global wages. It is connected with a high (low) share of wages in Section P (Section L) and its global production. The annual rates of growth of income multipliers are often positive, which indicates a growing impact of final demand on wages. It occurs particularly in Sections F, G, H, and L, which have the lowest value multipliers in 2010. These growing values suggest that the share of wages in sectors grows faster than the share of production.

Table 5.*Labour multiplier*

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Annual growth
A	0.14	0.13	0.12	0.10	0.08	0.07	0.07	0.07	0.06	0.06	-9.1%
B	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-4.9%
C	0.07	0.06	0.05	0.05	0.04	0.05	0.04	0.04	0.04	0.04	-5.7%
D	0.03	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.01	0.02	-6.4%
E	0.03	0.02	0.03	0.03	0.03	0.02	0.03	0.02	0.02	0.03	-1.7%
F	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	-5.7%
G	0.06	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	-3.4%
H	0.05	0.04	0.03	0.03	0.03	0.04	0.03	0.03	0.02	0.02	-8.6%
I	0.05	0.05	0.06	0.06	0.07	0.07	0.06	0.06	0.05	0.05	-0.6%
J	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	-5.3%
K	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	-9.3%
L	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.9%
M	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	-2.0%
N	0.04	0.03	0.05	0.04	0.04	0.05	0.04	0.05	0.04	0.04	0.2%
O	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.6%
P	0.05	0.05	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.05	0.0%
Q	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	-2.8%
R	0.05	0.05	0.06	0.06	0.07	0.07	0.05	0.05	0.07	0.08	3.5%
S	0.09	0.07	0.09	0.08	0.07	0.07	0.06	0.07	0.06	0.06	-4.2%
CoV*	61.0%	66.9%	65.7%	55.3%	55.3%	52.9%	51.1%	55.2%	57.4%	62.1%	-1.2%

*Coefficient of variation.

Source: Our own calculation.

The labour multiplier is most pronounced in Section R (other service activities) with a value of 0.083, implying that a 1 unit increase in final demand for these service activities generates an employment increase in the whole economy of more than 0.08 unit. In other world 100 MNT

increase in final demand in Section R increases employment by 8 persons. The values of the labour multiplier are strongly influenced, apart from IO flows, by the labour intensity of production - the higher/lower the labour intensity (which is the inverse of labour productivity), the higher/lower the labour multiplier. The high position of Section R suggests high work intensity (low productivity).

The annual rates of growth of labour multipliers are only negative, indicating a declining impact of final demand on employment and a corresponding decline in the share of employment in output. As the work intensity (measured as a share of employment in output) decreases, the productivity of work increases, which is a positive sign for Mongolian economy.

Table 6.
Gross Value-added multiplier

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Annual growth
A	0.83	0.86	0.89	0.92	0.9	0.84	0.85	0.84	0.82	0.83	-0.5%
B	0.68	0.58	0.64	0.65	0.63	0.7	0.71	0.68	0.65	0.68	0.8%
C	0.72	0.69	0.72	0.76	0.75	0.75	0.72	0.72	0.7	0.7	-0.2%
D	0.76	0.74	0.7	0.78	0.63	0.64	0.67	0.57	0.56	0.56	-3.6%
E	0.71	0.72	0.76	0.78	0.74	0.63	0.72	0.68	0.66	0.66	-1.4%
F	0.51	0.46	0.52	0.5	0.52	0.53	0.54	0.47	0.43	0.46	-0.9%
G	0.79	0.84	0.86	0.86	0.83	0.79	0.77	0.76	0.72	0.75	-1.5%
H	0.61	0.56	0.58	0.51	0.61	0.61	0.64	0.55	0.52	0.5	-1.1%
I	0.58	0.6	0.69	0.74	0.72	0.74	0.72	0.69	0.65	0.67	1.1%
J	0.75	0.75	0.72	0.72	0.71	0.69	0.63	0.63	0.59	0.59	-3.0%
K	0.83	0.8	0.9	0.88	0.9	0.85	0.86	0.85	0.8	0.83	-0.3%
L	0.91	0.92	0.9	0.92	0.91	0.9	0.9	0.89	0.89	0.88	-0.5%
M	0.66	0.67	0.78	0.67	0.74	0.72	0.71	0.68	0.62	0.64	-0.8%
N	0.72	0.63	0.73	0.71	0.68	0.67	0.67	0.65	0.6	0.58	-1.8%
O	0.77	0.77	0.77	0.8	0.75	0.79	0.71	0.75	0.74	0.71	-0.9%
P	0.84	0.86	0.89	0.88	0.89	0.87	0.88	0.87	0.85	0.87	0.0%
Q	0.74	0.72	0.79	0.75	0.75	0.74	0.7	0.65	0.64	0.68	-1.7%
R	0.8	0.78	0.88	0.87	0.85	0.78	0.72	0.77	0.75	0.76	-1.3%
S	0.74	0.68	0.83	0.84	0.81	0.76	0.76	0.73	0.69	0.7	-0.8%
CoV*	13.3%	16.4%	14.7%	15.7%	14.7%	12.9%	12.6%	15.6%	17.2%	16.9%	

*Coefficient of variation.

Source: Our own calculation.

Finally, the gross value added (GVA) multiplier is highest for Section L (real estate) at 0.87 and Section P (education) at 0.86, demonstrating these sectors' significant contributions to the overall creation of economic value added. This is the most interesting of all the multipliers because, contrary to the output multipliers, it has the potential to stimulate GDP. It may seem that sectors with a high output multiplier will also have the greatest potential to contribute to GDP. However, this is not the case, as evidenced by the different positions of the sectors in the first and last columns of Table 6. The negative relationship between these two multipliers is confirmed by the correlation coefficient, which is equal to -0.48 (for 2019) and is statistically significant. The negative correlation between output and GVA multipliers results from the fact the sectors that boost output the most may, due to their high intermediate consumption, have a relatively low GVA multiplier. Section L offers the best evidence of this, which is in

one of the last places in terms of output multipliers and in the first place in terms of GVA multipliers. This is because this section's share of GVA in output is the highest (at 79%), in contrast to, for example, Section F, for which the share of GVA in output is only 19%. Therefore, Section F, which had a relatively good record in terms of output multipliers, is in last place in terms of GVA multipliers.

The above observation shows that the values of multipliers are strongly influenced by the shares of a given variable (wages, employment, GVA) in output. In general, the higher/lower the share, the higher/lower the value of the multiplier. We showed earlier that this depreciates sectors with high material intensity (like F and H sectors being in the last positions in terms of GVA multipliers). However, it also depreciates sectors with high productivity such as B and L sectors being in the last positions in terms of labor multipliers. This is why we decide to calculate type I multipliers by dividing income, labour, and GVA multipliers (Table 7) by the share of a given variable in output (Miller, Blair, 2009).

Table 7.

*Output, income, gross value-added type I multiplier in 2019**

	Output multiplier	Income multiplier	Labour multiplier	Value-added multiplier
A	132	181	115	125
B	140	165	255	133
C	178	220	370	250
D	195	197	215	228
E	159	133	139	153
F	164	175	203	242
G	134	126	119	125
H	131	135	145	141
I	172	144	143	185
J	147	152	185	151
K	134	126	144	124
L	131	232	930	112
M	143	128	141	146
N	170	160	144	208
O	118	109	110	112
P	131	108	109	116
Q	131	110	114	123
R	139	113	106	123
S	166	140	121	167

Source: Our own calculation.

*value of original multipliers from Table 3-6 divided by the share of wages/employment/GVA in output and multiplied by 100 (for simplicity of interpretation).

The type I output multiplier showing how global production reacts to changes in the final demands of given sectors is the same as in Table 3 (with the highest value for D sector). The type I income multiplier is the highest for the L (real estate) sector, showing that 100 MNT growth in L sector wages (triggered by growth in final demand) increases the wages in the whole economy by 232 MNT. Type I labor multiplier is the highest in the real estate (Section L), in which employment growth by 100 persons increases total employment by 932 persons. On the other hand, processing industry (Section C) has the highest GVA

multiplier by showing that 100 MNT GVA growth in the sector increases the GVA in the whole economy by 250. **These sectoral differences become clearer when comparing the full set of type I multipliers across industries, as illustrated in Figure 2, which separates economic and social factors of growth.**

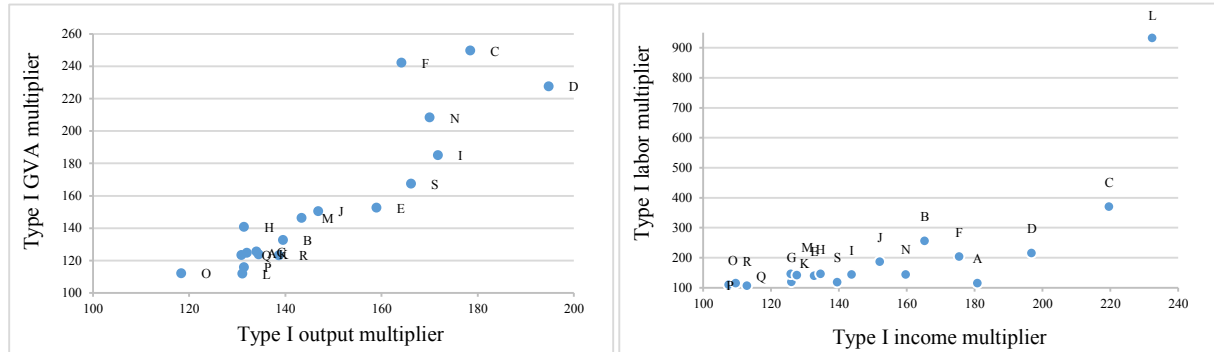


Figure 2. Output, income, labor, gross value-added type I multipliers in 2019 with division into economic (left chart) and social (right chart) factors of growth.

Source: Own study based on data from Table 7.

Suppose the income and labour multipliers are social-oriented inter-sectoral flows and output, and GVA multipliers are economic-oriented. The left graph shows that the sectors driving Mongolia's economic flows and supply chains are the C and D sectors, followed by the F, N, I, S, and E sectors. The right graph shows that the key sector supporting the social flows is primarily the L (with very high labour productivity), followed by the C and D sectors. From both charts, the least important in the context of supply chains are non-market services, mainly public services (Section O, P, Q).

It is worth noting that the non-mentioning above sectors of agriculture (Section A) and mining (Section B) have the highest contribution to GDP (cf. Fig. 1). Despite this, their role in input-output analysis focusing on intersectoral flows is low. In the case of mining (Section B), this is because most of the production is exported, so it does not participate in the domestic supply chain. On the other hand, agriculture (Section A) is primarily consumed in the domestic market.

4. Discussion and conclusion

In this paper, we identified the key sectors in the Mongolian economy that are understood as having their output used as an intermediate product in other sectors' production processes. From this perspective, the most important sectors in Mongolia are processing industries (Section C) and electricity, gas, steam, air conditioning supply (Section D). These sections are particularly susceptible to fluctuations in the business cycle, with changes in demand having significant implications for the entire industrial ecosystem.

While the above-mentioned industry sectors are the leading suppliers and consumers of global production, the service sectors significantly impact wages, employment, and value added in the Mongolian economy. Simple multipliers analysis shows that the increase in final demand will result in the highest growth in wages in education (Section P), employment in other services (Section S), and value-added in real estate (Section L) and education (Section P). We were surprised by these results, especially by the different positions of sections in the ranking of output and GVA multipliers. We expected that sections with high output linkages would have high GVA linkages. However, results show something opposite – sections with high output multiplier values have low GVA multipliers. The reason is that simple GVA multiplier depreciates sectors with high material intensity, like energy production (Section D) or particularly construction (Section F), and appreciates sectors with low material intensity such as real estate (Section L) or education (Section P). A similar inconsistency applies to simple labour multipliers which depreciates sectors with high productivity, mining (Section B) and real estate (Section L). **It is important to note that sectors such as real estate and finance contain significant asset-driven valuation components (e.g., imputed rents), which do not necessarily reflect productive economic activity or employment generation. As a result, labour multipliers in these sectors may be distorted and should be interpreted with caution, as high output or value-added levels may not translate into proportional labour demand.** We calculated first type multipliers to bypass these biases of simple multipliers. The results show that the sectors most driving Mongolia's economic flows and supply chains are the C and D sectors (having the highest value of output and GVA first-type multipliers). The key sector supporting the social flows is real estate (L) with very high labour productivity, followed by the C and D sectors. On the other hand, the least important in the context of production supply chains are non-market services, mainly public services (Section O, P, and Q). This is interesting that the mining sector (B) having the highest contribution to GDP (from all sections of ISIC) are not mentioned above as its role in intersectoral flows is low. This is because most of the production (nearly 90%) is exported, so it does not participate in the domestic supply chain.

In literature there are limited studies explored the effects of industry linkages in Mongolia. The Global Trade Analysis Project (GTAP) created the first IO table for Mongolia, based on the 2005 cross-sectoral balance table produced by the National Statistical Office of Mongolia (Begg et al., 2012). Since then, only a few studies have used this table to analyze the impact of specific sectors on the Mongolian economy: Hong-Bi (2013) uses it for R&D analysis, Tungalag et al., (2019) examine the impact of copper production on other sectors of the economy (Byambasuren, 2022), studies the influence and interrelationship between the financial sector and other leading sectors, Zagdbazar et al. (2018), measured the FDI inflow. The methodology most similar to ours was used in the article by Tegshjargal & Tsend-Ayush (2015). This article (which is accessible only in Mongolian languages), uses tables from 2015 and has a limited range because it includes a disclaimer that the report reflects the views of the

employees who conducted the study based on their respective positions. As a result, the backward linkage effects (comparable with output multiplier in this article) in the top three places are sections: E (water supply, sewage disposal systems, waste management, and sanitizing operations), N (administrative and support service activities) and F (construction). On the other hand, the manufacturing (C); electricity, gas, steam, and air conditioning supply (D); and financial and insurance activities (K) sectors rank first in terms of forward linkage effects. The agricultural sector's efficiency is weak compared to that of other sectors in terms of backward and forward linkages. Among the leading sectors, the sector with the highest direct impact is the electricity, gas, steam, and air conditioning supply sector (D), while the direct impact of the manufacturing (C) sector is weakest. Byambasuren (2022) conducted the study 'influence and interrelationship between the financial sector and other leading sectors', defining forward and backward linkages using the IO table for 2010-2019. Their results indicate that the manufacturing (C); electricity, gas, steam, and air conditioning (D); and administrative and support service activities (N) sectors are leading in backward linkages.

In our analysis we could confirm that C, D, F, and N sectors have the greatest potential to stimulate of economic growth (as shown in left panel of Fig. 2). Time series analysis allows additionally for the observation of increasing/decreasing position of the multipliers what shows a structural change in the Mongolian economy. Decreasing position in output multipliers, like in public service sectors (O and Q), but also arts services (R) and water supply (E), means that less and less global production is needed to satisfy the growing final demand in this section. This might mean that some positive structural change happened (but also that more demand is satisfied by imports).

We also identify which sections may have the most significant impact on social development, as measured by the potential to increase wages and employment across the economy. The Section L connected to the real estate market should be mentioned here. This is the section with the highest productivity, which supports the wage and employment flows the most.

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IS ORGANIC FARMING BENEFICIAL TO POLISH FARMERS? A CASE STUDY FOR MAŁOPOLSKA

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Purpose: The aim of the study was to diagnose the impact of organic production on the economic and social situation of farmers and to identify the reasons for the low popularity of organic farming in Poland.

Design/methodology/approach: The survey was conducted between February and August 2024 in the Lesser Poland (Małopolska) province of Poland among 104 farmers engaged in organic and conventional production. A survey method was used, conducted by means of a questionnaire that includes questions about the financial situation, motivations for choosing a production system, and the barriers to and challenges of running an organic farm.

Findings: The results of the study showed that organic farmers have a higher level of financial satisfaction and greater economic stability compared to conventional farmers. The main barriers are high production costs, complicated certification procedures, and a limited market.

Research limitations/implications: The study's conclusions indicate that the development of organic farming in Poland requires coordinated action by public institutions, involving simplification of certification processes, increasing financial support, and conducting effective campaigns to promote organic products. Data analysis was conducted using the χ^2 test to determine the relationship between farm type and socioeconomic variables.

Originality/value: The article addresses promoting public awareness of the benefits of organic food production, which is key to increasing demand for organic products and improving the economic situation of farmers.

Keywords: organic agriculture, agricultural policy, economics of agricultural production, prosperity.

Category of the paper: Research paper.

1. Introduction

Organic farming can be understood as a system of agricultural production based on natural processes and raw materials, whose main goal is to provide high-quality food with minimal environmental impact. Its methods promote responsible use of energy and natural resources,

the protection of biodiversity, maintaining ecological balance, improving soil fertility, and maintaining good water quality. In addition, organic farming regulations place great emphasis on animal welfare, requiring farmers to ensure that animals are kept under conditions that meet their natural behavioural needs. European Union regulations in this area ensure uniform standards for organic production throughout the EU. Their goal is not only to meet the growing demand for certified organic products but also to create a fair market for farmers, distributors, and dealers (European Commission, Agriculture and Rural Development, n.d.).

In the sixth report of the Intergovernmental Panel on Climate Change (IPCC), published in the second half of 2021, the authors clearly state that there is an almost direct relationship between cumulative greenhouse gas (GHG) emissions from human activities and global warming (Wrzaszcz, Prandecki, 2020). According to their assessment, in order to stabilize the anthropogenic increase in global temperature at current levels, it is necessary to achieve net-zero (CO₂) emissions and significantly reduce emissions of other greenhouse gases. The transition to a green economy that is environmentally friendly and enables the reduction of GHG emissions is, in the context of ongoing climate change, one of the most important economic and environmental challenges of today's world (Wrzaszcz, Prandecki, 2020). Organic farming has certain economic, social, and environmental benefits. It is one of the components of the sustainable development of rural areas. In Poland, due to the fragmented agrarian structure and the low use of chemicals during tillage, the conditions for progress in the existing production system are favourable. Nevertheless, the further development of organic farming depends mainly on the demand for organic food. According to consumer surveys, organic products command the highest price on the market. In addition, the determinant of the structure and volume of demand is perceived by consumers as high.

Organic agriculture in developed countries plays an important economic, social, and environmental role, and contributes to the achievement of Sustainable Development Goals (SDGs), as well as realization of the Green Deal strategy. Agricultural practices must and will change to meet the United Nations Sustainable Development Goals. Sustainable agriculture and food systems should, in addition to providing adequate nutritious food for all, minimize harmful effects on the environment and also provide farmers with decent living conditions. Transformational models, such as organic farming, offer numerous benefits – improving soil quality, reducing pollution, increasing biodiversity, and also improving farmers' incomes. In many cases, however, crop yields are lower, raising questions about the ability to ensure global food security. Organic farming, while not a perfect system, is a useful part of such a transformation (Eyhorn et al., 2019). Organic farming systems are more cost-effective, environmentally friendly, and provide high-quality food with fewer pesticide residues, and sometimes are completely free of them. A combination of organic and innovative farming systems is needed for sustainable production. Preliminary research suggests that organic farming improves environmental quality and offers additional social benefits, such as increased biodiversity and improved soil quality. Organic farming, despite its controversial past,

is increasingly recognized as a key element in the pursuit of sustainable development. Its growing presence in the grocery market - both in the food and beverage segments - is evidence of growing consumer interest in organic solutions (Reganold, Wachter, 2016).

Organic farming contributes to the popularization of the production and consumption of quality food and the promotion of a healthy lifestyle (Brzezina et al., 2017). The growing interest in organic food production is making the public increasingly aware of issues related to food safety and its economic and environmental impact. This is leading to an increase in demand for healthy food, which is produced by farms that do not use mineral fertilizers and pesticides.

Consumers are choosing to buy “eco” products for a number of reasons, primarily health consciousness (Das et al., 2020). Perceived naturalness as well as environmental concerns and ethical motivations are also important factors in the selection of the aforementioned products. Intrinsic motivation, integrity and external regulation, environmental concerns and trust significantly influence consumers' propensity to buy organic food (Tandon et al., 2020). Soroka and Wojciechowska-Solis (2019) provide empirical evidence on consumer motivation to purchase organic food, with a focus on the influence of lifestyle factors. The survey identified key reasons for choosing organic products: lack of harmful substances and health benefits, especially among physically active people. Among less active consumers, taste is a priority.

Savi (2024) reviewed the factors influencing consumers' organic food purchasing behaviour. He emphasizes that the growing demand for organic food is driven by concerns about health and nutrition, great taste and environmental awareness. The study identified three key dimensions influencing consumer decisions: price, time and eco-labelling. In addition, it was noted that consumers with higher education and income levels are more likely to recognize the benefits of organic food and are willing to pay a higher price for it, especially those who are environmentally conscious and believe that their choices will have an impact on future generations.

A study by Wojciechowska-Solis and Barska (2021) shows that consumers choose to buy organic products mainly because of their health benefits, high nutritional content and lack of harmful additives and preservatives. Growing environmental awareness also plays an important role - consumers are increasingly paying attention to the impact of food production on the environment, animal welfare and social aspects.

The literature identifies a number of factors influencing the perceived credibility of organic food, key among them being labelling, certification, place of purchase, country of origin, brand, price, communication, product category and packaging. Of these factors, labelling, certification and country of origin have been studied in detail. Certification and label indications play a key role in building consumer confidence in organic foods. They provide a guarantee of the quality and authenticity of the product, which influences the perception of its value and purchasing decisions. Consumer confidence in organic food is largely based on the existence of recognizable labels and certifications that provide confirmation of compliance with organic

production standards. The perception of a product has a significant impact on purchase intentions and consumption decisions, as highlighted by studies showing a strong link between product credibility and consumers' willingness to choose organic food. Transparency in terms of certification, labelling and country of origin strengthens confidence in the product, which in turn increases the likelihood of buying it (Rejman et al., 2023).

Based on the literature review, it is possible to distinguish several major categories of organic food consumers whose market behaviour is driven by awareness of the benefits of choosing organic products, thus contributing to sustainable development. There are four groups of organic consumers: Eco-activists - driven by concern for their and their family's health, choose organic foods to avoid artificial additives and potentially harmful substances. Eco-dietitians - focus on the nutritional value of products, treating organic food as part of a healthy diet to prevent disease. Eco-traditionalists - choose organic products primarily for their better, more natural taste compared to conventional foods. Eco-innovators - consumers who are driven by environmental concerns and view the choice of organic products as a conscious act to protect the planet (Wojciechowska-Solis, Barska, 2021). Environmental concerns are also an important factor in the selection of the aforementioned products. Consumer awareness of sustainability and the benefits of organic farming is growing. Despite its many advantages, the introduction of organic farming comes with some technological limitations and other difficulties (Łuczka, 2023).

The benefits of organic production, combined with consumer expectations and the construction of the necessary legal and institutional framework are resulting in the development of organic farming in the European Union. Analysing data on the area of farmland cultivated organically in the European Union, there is a clear upward trend (Table 1). In 2022, about 17 million hectares of land in the EU were dedicated to organic crops, accounting for 10.5% of the total agricultural area. Switzerland saw an increase of 52.8%, increasing its organic area to 185 224 hectares. Norway, in contrast, was one of the few countries to see a decline in organic acreage, down 16.7%.

Poland stands out in the European Union as the only member country where the area of land devoted to organic farming has shrunk over the period from 2012 to 2022. During this period, the acreage of organic crops has decreased by 15.4% - from 655 459 hectares in 2012 to 554 632 hectares in 2022. This phenomenon is worrying, especially in the context of the pan-European growth trend, where most countries are rapidly expanding organic farming. Examples include France, where organic acreage grew by 178.9%, and Portugal, which saw an increase of as much as 278.4%. Even countries such as Romania (+123.6%) and Hungary (+145.4%) have significantly increased their organic areas (Fig. 1). The observed regression in Poland prompts key research questions: Why are Polish farmers not seeing the benefits of organic farming?; Does Poland lack effective regulations to support organic farming?; Is Poland inefficiently managing funds from the Rural Development Programme (RDP)?; Are farmers in Poland unable to make a living from organic farming?; and, Is a lack of satisfaction with organic farming leading farmers to abandon the system?

Table 1.*Total area of organically farmed agricultural land in the EU (in ha.)*

Countries	Organic area (ha)		2012-22 (% change)
	2012	2022	
EU	9 457 886	16 898 463	78.7
Belgium	59 718	103 437	73.2
Bulgaria	39 138	110 441	182.2
Czechia	468 670	563 527	20.2
Denmark	194 706	300 057	54.1
Germany	959 832	1 630 984	69.9
Estonia	142 065	231 011	62.6
Ireland	52 793	95 701	81.3
Greece	462 618	924 853	99.9
Spain	1 756 548	2 675 331	52.3
France	1 030 881	2 875 500	178.9
Croatia	31 904	129 374	305.5
Italy	1 167 362	2 349 475	101.3
Cyprus	3 923	7 749	97.5
Latvia	195 658	312 820	59.9
Lithuania	156 539	271 329	73.3
Luxembourg	4 130	8 255	99.9
Hungary (1)	130 607	320 517	145.4
Malta	37	66	78.4
Netherlands	48 038	80 086	66.7
Austria (2)	533 230	705 800	32.4
Poland	655 499	554 632	-15.4
Portugal	200 833	759 977	278.4
Romania	288 261	644 520	123.6
Slovenia	35 101	53 202	51.6
Slovakia	164 360	253 156	54.0
Finland	197 751	339 459	71.7
Sweden	477 684	597 204	25.0

*(1) Break in time series, 2022.

(2) Austria: 2022 data taken directly taken from Federal Ministry of Agriculture, Forestry, Regions and Water Management.

Source: (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Developments_in_organic_farming).

The purpose of the article is to diagnose the impact of organic production on the economic and social situation of farmers and to identify the reasons for the low popularity of organic farming in Poland.

2. Economic viability of organic agriculture

The analysis of available texts, data and documents shows that organic farming is a reasonable economic alternative for farmers. One can see a clear increase in interest in this form of farming practically throughout Europe, which is confirmed by numerous statistics and the development of organic certification. However, Poland stands out from the rest of Europe, as interest in organic farming is not as widespread as in most European countries.

The growing number of organic farms is due to two main reasons. The first is the growing public awareness of healthy eating, while the second factor is the financial subsidies that these farms receive. Under the conditions of a market economy, where the demand and supply of organic products are shaped by the market, it is important that these farms are managed in a rational way, which is a complicated task and subject to dynamic changes. Profitability in this system depends on a number of internal factors, such as soil quality, available equipment, resources and labour, as well as external factors, such as location in relation to markets and European Union agricultural policy and national regulations. In addition to the farmer's ecological awareness, the key factor prompting a change in the farming model and a shift to organic production is primarily the subsidies available under programmes supporting “organic farming”. Farmers can obtain detailed information and preliminary analyses from agricultural consultants who work at provincial Agricultural Advisory Centres and their local branches (Sazońska et al., 2021).

Reganold and Wachter (2016) showed that no agricultural method achieves the level of sustainability that organic farming does, whose priority is not just to maximize yields, but to provide safe and valuable food produced with minimal environmental impact. Organic farming also strives for economic viability while adhering to a social standard. A comparative analysis of conventional and organic production methods revealed serious drawbacks of conventional agriculture, such as high-water pollution, ecosystem instability, soil deterioration and poor biodiversity. A farmer, when deciding to implement a 5-year organic plan within the framework of certain packages and their variants, must follow the rules provided for these packages. To be eligible for organic payments, a farmer must have an ID number assigned by the ARMA, have at least 1 hectare of farmland and commit to an agri-environmental plan. In the event that one farmer alone is unable to meet these conditions, he can do so jointly with other farmers. Production under all packages must be carried out in accordance with the regulations on organic farming, and meet the requirements for the production of organic products. The main sources of support for organic production in Poland are shown in Table 2 (Sazońska et al., 2021).

Table 2.

Amount of organic payment rates from March 2024

No.	Organic farming packages	Variants of organic farming	Payment rates
1.	Package 1 Agricultural crops in conversion		1 697 PLN/ha
2.	Package 2 Vegetable crops in conversion		3 021 PLN/ha
3.	Package 3 Herbaceous crops in conversion		1 673 PLN/ha
4.	Package 4 Orchard crops in conversion	4.1.1 Primary orchard crops in conversion	1 856 PLN/ha
		4.1.2 Berry crops in conversion	2 495 PLN/ha
		4.2 Extensive orchard crops in conversion	1 326 PLN/ha
5.	Package 5 Forage crops on arable land in conversion		1 638 PLN/ha
6.	Package 6 Permanent grassland in conversion		1 043 PLN/ha
7.	Package 7 Post-conversion agricultural crops		1 571 PLN/ha
8.	Package 8 Post-conversion vegetable crops		2 391 PLN/ha
9.	Package 9 Post-conversion herb crops		1 856 PLN/ha

Cont. table 2.

10.	Package 10 Orchard crops after the conversion period	10.1.1 Basic post-conversion orchard crops	1 961 PLN/ha
		10.1.2 Post-conversion berry crops	2 213 PLN/ha
		10.2 Extensive orchard cultivation after the conversion period	1 326 PLN/ha
11.	Package 11 Forage crops on arable land after the conversion period		1 504 PLN/ha
12.	Package 12 Permanent grassland after conversion period		1 043 PLN/ha
13.	Package 13 Premium for sustainable crop-animal production		573 PLN/ha

Source: Stawki płatności - Agencja Restrukturyzacji i Modernizacji Rolnictwa - Portal Gov.pl (www.gov.pl).

Within the framework of the “Organic Farming” programme, the farmer has the opportunity to adapt three different types of organic commitments, which group packages according to the type of agricultural land used, namely:

- commitment on arable land (packages 1, 2, 3, 5, 7, 8, 9, 11 and variants 4.1.2. and 10.1.2.),
- commitment in orchards (options 4.1.1., 4.2., 10.1.1., 10.2.),
- commitment on permanent grassland (packages 6 and 12).

A farmer has the opportunity to simultaneously implement more than one commitment, including more than one commitment of the same type (for example, two commitments on arable land). Under organic payments, the principle of degressivity applies: 100% of the basic rate for an area from 0.10 ha to 50 ha, 75% of the basic rate for an area above 50 ha to 100 ha, and 60% of the basic rate for an area above 100 ha (Szońska et al., 2021).

However, the growing popularity of organic and healthy lifestyles is helping to keep prices of organic products high. Consumers are increasingly willing to pay a higher price for organic products, especially when the product has quality certifications and geographical indications. For example, a study on clementine cultivation in Italy found that organic methods were associated with better economic performance, mainly due to the price premium obtained for organic and GI-protected products (Falcone et al., 2020). A systematic analysis of organic olive growing in Spain confirms the economic viability of organic practices, indicating their potential benefits in terms of profitability and overall economic performance compared to conventional farming systems (Martín-García et al., 2023).

The transition to organic farming in the European Union poses significant challenges. Farmers using organic farming methods often face limited nutrient availability, making it difficult to properly nourish plants. Additionally, pest and weed control can be more demanding under organic conditions, which can consequently result in lower yields compared to conventionally grown crops (Zieliński et al., 2024). Financial support under the Common Agricultural Policy (CAP) in the form of subsidies has played an important role in overcoming the initial difficulties associated with organic farming. These measures have helped to increase the economic stability of organic farms and reduce the income gap with conventional agriculture, facilitating the implementation of more sustainable farming practices (Guth et al., 2020). Financial incentives and subsidies contribute significantly to improving economic

performance in organic farming, increasing the competitiveness of organic products on the market (Łuczka-Bakuła et al., 2021).

In the context of the European Union, support under the Common Agricultural Policy (CAP) has played a key role in improving the profitability of organic farms. CAP subsidies help narrow the income gap between organic and conventional farms, making it easier for farmers to shift to more sustainable farming practices. Despite higher prices, demand for organic food remains high. Studies show a strong link between consumers' willingness to pay a higher price and organic farmers' incomes, which translates into greater producer satisfaction and profitability (Pavlovich, 2020). Nonetheless, disparities in market access and competition from conventional agriculture remain significant challenges, underscoring the need for further policy and market support to increase the viability and competitiveness of organic products (Ghanghas et al., 2021).

3. Research methodology and characteristics of the study group

The survey was conducted between February and August 2024. The general population of the survey was defined as farmers of Małopolska. The survey was conducted among certified organic farmers and conventional farmers. The survey population amounted to $n = 104$ units. The sampling was purposive, and the participation of both certified and non-certified farmers was assumed. A snowball mechanism was used, whereby an initially selected small group of respondents is surveyed and each member of this group identifies (recommends) other individuals belonging to the general population to be surveyed further (Szreder, 2004). The decision for this type of sampling was due to specific conditions in the survey population, which is characterized by distrust of survey research.

The research tool was a survey questionnaire, which included 21 questions.

The questionnaire was divided into sections: 5 metric questions, 1 question filtering the approach to agricultural production, and 15 questions on the socioeconomic conditions of the agricultural production implemented. The survey included 14 single-choice questions, 1 open-ended question and 4 cafeteria questions. The questions pertained to the evaluation of job satisfaction, assessment of the financial situation, additional income from non-agricultural activities and perception of the development of organic farming demand on the market. The survey used a semantic scale.

Survey responses were collected and then analysed using Microsoft Excel 2016. The results of the survey were presented in the form of tables and figures. The χ^2 test (Słowińska, 2019) was used for statistical analysis. It was used to test the relationship between the respondents' answers and the criterion, which was the system of farming, assuming a significance level of $\alpha \leq 0.05$. Before calculations were made, the homogeneity of variance was tested with the

Shapiro-Wilk test and the normality of the distribution with Levene's test. 104 respondents participated in the survey. The detailed composition of the sample is shown in Table 3.

Table 3.
Characteristics of the study group

Characteristics		Share [%]	Group of farmers	
			Organic agriculture	Conventional agriculture
Gender	Women	38.5	61.5	30.8
	Men	61.5	38.5	69.2
Age [years]	Under 18	3.8	0	5.1
	18-25	30.8	30.8	30.8
	26-35	30.8	53.9	23.1
	36-45	13.5	7.7	15.4
	46-60	15.4	7.7	17.8
	Over 60	5.8	0	7.7
Education	Primary	9.6	7.7	10.3
	Vocational	21.2	0	28.1
	Secondary	36.5	23.1	41

Source: own research.

The analysis using the chi-square test shows that all differences between conventional farmers and those using organic production methods are statistically significant. This means that the observed differences are not random, but indicate real relationships between the variables under study.

Several differences between organic and conventional farmers can be discerned in the sample. Above all, organic farmers are distinguished by a slightly higher level of education. Increased organic awareness, openness to innovation and better knowledge of regulations related to certification may be due to education, which translates into their willingness to farm organically. In addition, there is an apparent trend toward higher incomes among organic farmers. This is a result of the ability to obtain higher prices for organic products, which are increasingly popular in the market, especially in the European Union. Organic products are perceived as healthier and more environmentally friendly, which increases their attractiveness in the eyes of consumers, and thus promotes higher profitability for organic farms.

4. Comparative analysis of the impact of agricultural production systems on the economic and social situation of organic and conventional farmers

In the completed survey, numerous differences were observed in the self-assessment of the socioeconomic situation of organic and conventional farmers. The results were interpreted separately for the group of organic farmers and the group of conventional farmers, which enabled a detailed analysis of the differences between the two categories. The first question in this section concerned the subjective assessment of the financial situation of the respondent's farm. A 10-point semantic scale was used to scale the answers to this question. A graphical

representation of the results is shown in Figure 3. “1” means the lowest rating, which may indicate a very bad financial situation for the farmer. “10” means the highest rating, which suggests a very good financial situation, full economic stability and no financial problems.

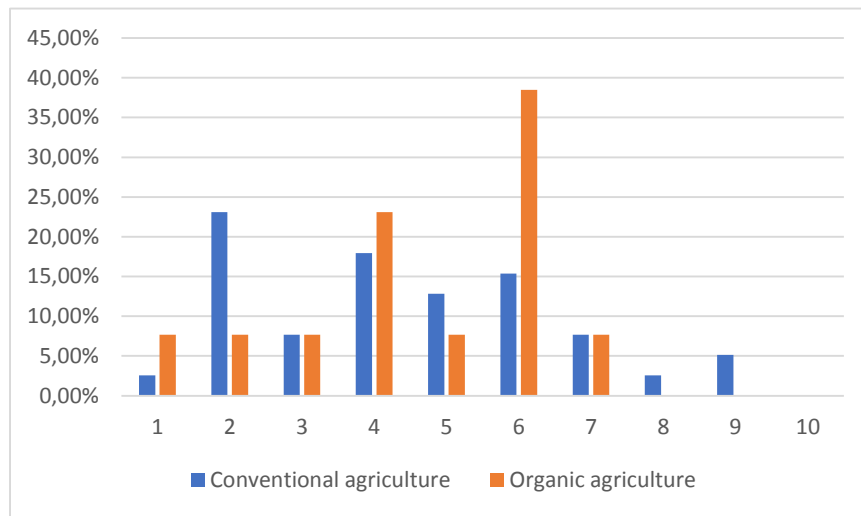


Figure 1. Farmer's assessment of financial situation.

Source: own research.

38.46% of organic farmers rated their financial situation as 6. The most common answer chosen by conventional farmers was 2, indicated by nearly 25% of respondents. Among conventional farmers, there was a higher percentage of ratings at the lower end of the scale (1-3). By contrast, on the upper end of the scale of 8-10, no organic farmer rated their financial situation higher than 7, while the highest rating among conventional farmers was 9. The overall distribution of ratings suggests that organic farmers perceive their situation to be more stable, while conventional farmers face greater economic challenges.

The next question referred to the level of job satisfaction (Figure 2). In this case, too, the 10-point Osgood scale was used.

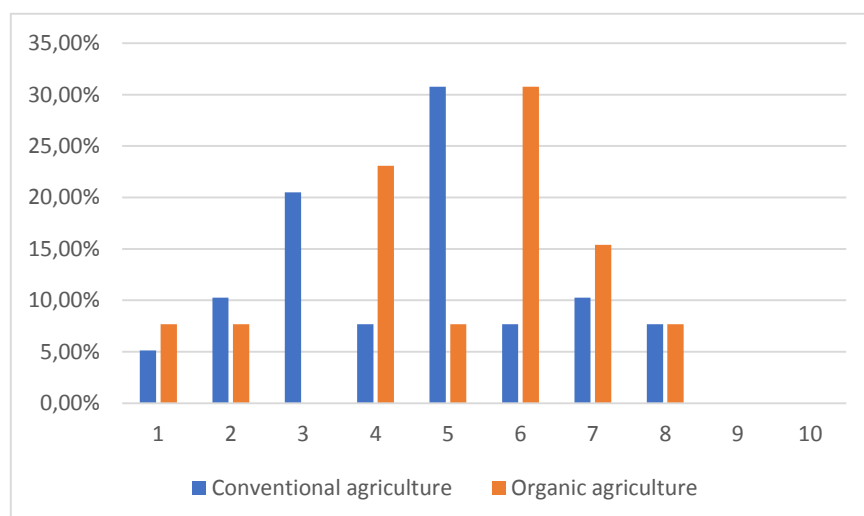


Figure 2. Level of job satisfaction - farmer's assessment.

Source: own research.

30.77% of organic farmers rate their job satisfaction as 6 points. The same percentage of conventional farmers, and also the largest percentage of conventional farmers, rate their job satisfaction as 5 points. This means that the level of job satisfaction is most often at a moderate level in both groups, although there is a higher percentage of ratings in the higher ranges (7-8) among organic farmers, which may be related to a greater sense of meaningful work resulting from concern for the environment and the growing demand for organic products. None of the farmers (both organic and conventional) gave ratings above 8, indicating that, despite the differences in satisfaction, both groups of farmers do not achieve full job satisfaction.

The next part of the analysis was carried out using the χ^2 test. The relationship between the respondents' answers and the criterion, which was the type of agriculture practised, was tested, assuming a significance level of $\alpha \leq 0.05$. Before calculations were made, the homogeneity of the variance was tested with the Shapiro-Wilk test and the normality of the distribution with Levene's test. For each studied characteristic, the null hypothesis was accepted, assuming no relationship between survey responses and the type of agriculture practised. However, the results of the χ^2 test, presented in Table 4, showed a relationship between some variables, which led in those cases to reject the null hypothesis and confirm significant statistical differences.

Table 4.

The results of the χ^2 test (assuming a significance level of $\alpha \leq 0.05$)

Question	Criterion	Answer	Value of p
Do you have income from non-agricultural activities?	type of agriculture	yes	3.11411E-10
		no	
How long have you been farming [years]?	type of agriculture	1 year or less	13.4576744
		2-5 years	
		6-8 years	
		9 years or more	
Is the yield of organic products produced greater than products without organic certification?	type of agriculture	yes	1.00894661
		no	
		the performance of organic products is comparable to conventional ones	
In your opinion, are organic food production costs more expensive than those for products without organic certification?	type of agriculture	yes	1.00894661
		no	
		the cost of organic food is comparable	
In your opinion, are organic products more expensive than products without organic certification?	type of agriculture	yes	0.96825397
		no	
		prices of organic products are comparable	
Do organic products sell at a premium price?	type of agriculture	yes	1.82010582
		no	
		I don't know	
		I'm not sure	

Source: own research.

Analysing the results in Table 3, the following conclusions can be identified:

There is a relationship between the type of agriculture practised and having income from non-agricultural activities, as shown in Figure 3. Organic farmers are more likely to engage in non-agricultural activities and earn additional income from them, which may increase their financial stability. Conventional farmers are more likely to rely solely on farming activities, which may suggest the need to promote income diversification in this group to improve their economic situation.

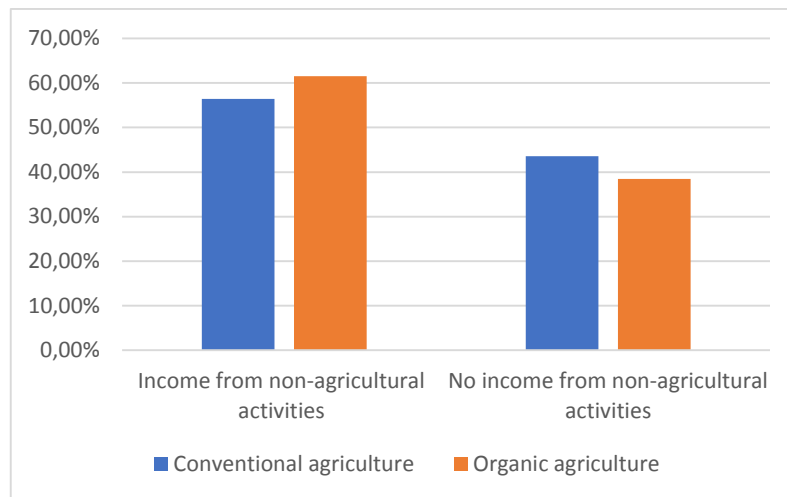


Figure 3. Farmers' declarations of receiving income from non-agricultural activities.

Source: own research.

There is a relationship between the length of time a farm has been in operation and the system under which it is farmed (Fig. 4). Based on the results, it can be concluded that organic farming is the system more often chosen by newly established farms, while conventional farms tend to last longer. In addition, conventional farming dominates on older farms, which may suggest a greater attachment to conventional production methods and a lower propensity to switch to an organic system. These differences may be due to economic factors, social factors and the level of organic awareness among farmers.

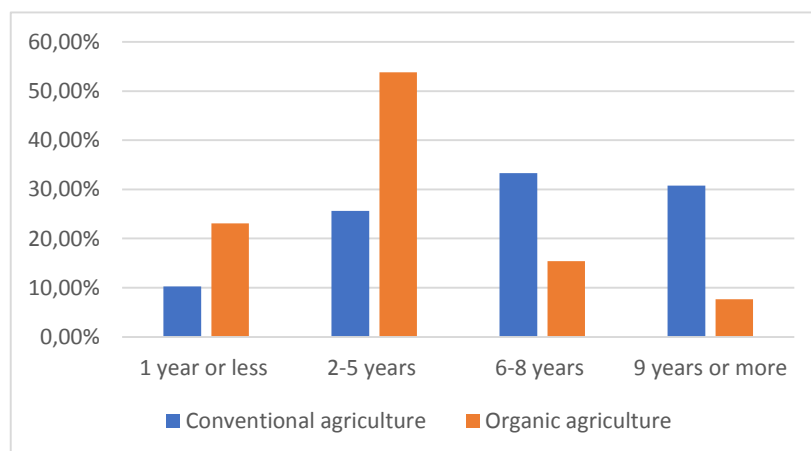


Figure 4. Length of time in operation.

Source: own research.

No correlation was found between the type of agriculture practised and farmers' opinions on the efficiency of organic production compared to the non-certified system. Similarly, there was no correlation between farmers' opinions on the higher cost of organic food production and the type of production used. There was also no relationship between the respondents' opinion on the higher price of organic products and the type of agriculture practised. In other cases, no such relationship was found either.

There is a relationship between the system of agricultural production used and the opinion regarding the “premium price” of organic products. This relationship is shown in Figure 5. Organic farmers are much more confident about the possibility of obtaining higher prices for their products, which probably motivates them to continue and develop organic production methods. Conventional farmers, in contrast, are less confident in this regard, which may be due to a lack of experience in the market for organic products or insufficient knowledge of the demand for such products.

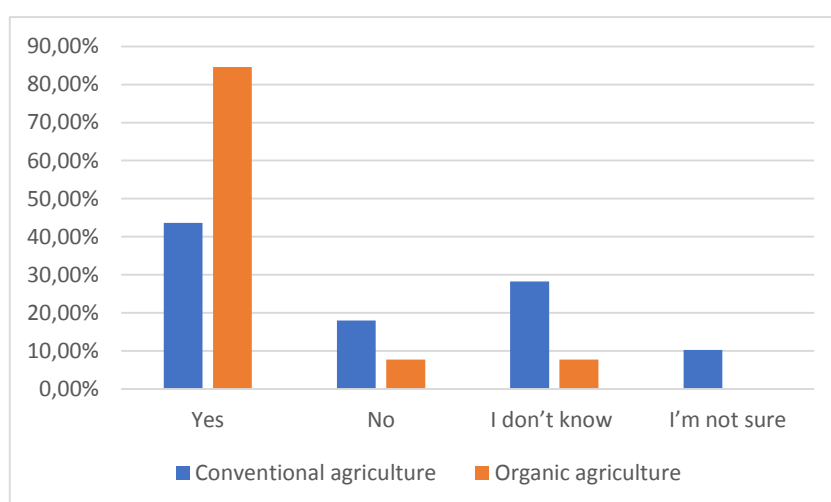


Figure 5. Farmers' opinion on the incidence of premium price for organic products.

Source: own research.

In the next step of the study, an attempt was made to diagnose farmers' motivations for choosing a certain type of agricultural production. Table 5 summarizes the motives that farmers identified when deciding to farm organically. The motive of “health of self and family” was the most important, as this answer was given by as many as 53.8% of the entire group of respondents, including 46.2% in the group of organic farmers and 51.2% in the group of conventional farmers. An equally important factor was “high prices for organic products”. Such a response was indicated by 40.4% of the surveyed farmers, with 46.2% in the group of organic farmers and 34% in the group of conventional farmers. The answer “high subsidies on organic farms” was indicated by 26.9% of respondents, with 15.4% of organic farmers and 27.9% of conventional farmers. The least important factor for the farmers surveyed was “other motives”, indicated by only 3.8% of respondents.

In Łuczka's study (Łuczka, 2023), the motives of greatest importance, with a rank of 3 and above on the Likert scale, were: "high subsidies for organic farms" (3.83), "pro-environmental lifestyle" (3.32), "own and family health" (3.27) and also belief system and ethics (3.0).

Table 5.

Motives of organic farming in the opinion of organic and conventional farmers

Motive	Average	Group of farmers	
		organic [%]	Conventional [%]
High subsidies for organic farms	26.9	15.4	27.9
Higher prices for organic products	40.4	46.2	34.9
Growing potential of the organic food market	30.7	46.2	23.3
Improving product quality	36.6	38.5	32.6
Self and family health	53.8	46.2	51.2
Other	3.8	7.7	2.3

Source: own research.

The purpose of the survey was also to find out the opinion of farmers regarding the factors that can prevent farmers from further abandonment of organic farming, as has been the case in Poland in recent years. This issue is important from a practical point of view, since the identification of the problem can contribute to preventive measures to eliminate the problem. The analysis shows that according to the respondents, the factors affecting the continuation of production in the organic system are "increased financial support," according to more than half of the respondents 55.8% (76.9% of farmers in the organic group and 45.2% in the conventional group). Another important factor according to 42.3% of respondents (30.6% of respondents in the organic farmers' group and 42.9% in the conventional farmers' group) is "simplification of certification procedures". A smaller number of people - 23.1% (15.4% in the organic farmers' group, 23.8% in the conventional farmers' group) believe that "Increasing the effectiveness of promotional policies for organic farming and food" is important (Table 6).

There are several key factors from the survey that could contribute to increasing the number of farmers in the organic system. A key element to continue farming in the organic system is financial support. It is therefore necessary to introduce additional financial mechanisms for organic farmers to ensure the financial stability of farms. Another measure could be the simplification and reduction of bureaucratic burdens, which could increase the number of organic farms. A further measure could be the promotion of organic farming. More effective promotional activities could help build consumer awareness, which could stabilize the market for organic products in the long run.

In addition, according to Łuczka's survey (Łuczka, 2023), measures such as increasing financial support (4.15), minimizing bureaucratic procedures and regulatory burdens (4.07), and supporting activities that serve to increase demand for organic products (4.03) were of high importance to all respondents. Among preventive measures, high importance was also attributed to such measures as increasing the effectiveness of organic food promotion policies (3.98), as well as improving the support system (3.88). This shows that the factors cited by farmers, which if changed could prevent farmers from further abandoning organic farming, are often repeated.

It is noticeable that organic farmers are less likely to point to bureaucracy and complicated procedures as obstacles. Only $\frac{1}{3}$ of them expect these processes to be simplified, which can be explained by the fact that they already have experience in dealing with certification requirements. They were able to go through these procedures and dealt with the formal requirements, and now benefit from certification, which provides them with access to premium markets. In contrast, almost 43% of conventional farmers indicate the need to simplify procedures, suggesting that one of the main problems holding them back from switching to organic farming is a fear of bureaucracy and an inability to deal with formal requirements. It is worth noting that conventional farmers often have a lower level of education, which may influence their perception of procedures as being more complicated than they really are. This is a clear indication to government authorities that the promotion of organic farming should take into account the simplicity and transparency of the certification process, and educational activities can help alleviate these concerns. Another important finding of the survey is the difference in expectations between organic and conventional farmers in terms of access to information. Nearly 25% of conventional farmers indicate a need for better knowledge of the market and more information from the media and those in power.

Table 6.

Proposals for measures to prevent farmers from abandoning organic farming in the opinion of organic and conventional farmers

Proposals for measures to prevent farmers from abandoning organic farming	Average	Group of farmers	
		ecological [%]	conventional [%]
Improving agricultural advice	17.3	15.4	16.7
Simplification of certification procedures	42.3	30.6	42.9
Increasing the effectiveness of agricultural and organic food promotion policies	23.1	15.4	23.8
Increasing financial support	55.8	76.9	45.2
Other	1.9	0	2.4

Source: own research.

The results of the survey, presented in Table 7, show differences in the perception of the problems of organic farming development by two groups of respondents: organic farmers and conventional farmers. The identified challenges indicate the variety of barriers that may influence the decision to implement or abandon organic farming. Interpretation of these results has important implications for the further development of organic agriculture and the design of policies to support the sector.

Organic farmers identified several significant problems that affect their ability to run their farms effectively. Among the most frequently mentioned were:

- Low public awareness: Lack of widespread knowledge among consumers about the health and environmental benefits of organic production will limit demand for organic products. Farmers see this as a key problem affecting the profitability and growth opportunities of their business.

- Fear of inspection: Organic certification involves regular inspections, which can be stressful and time-consuming. This fear discourages farmers from taking the risks associated with possible failure to meet rigorous standards.
- Low crop yields and high production costs: Organic farmers perceive productivity of their crops to be lower compared to conventional agriculture. Combined with higher production costs associated with, for example, the need to use natural crop protection products, organic farming becomes less profitable, especially in the short term.
- Low demand for organic products: Despite growing consumer awareness, the high price of organic products limits the availability of these products on the mass market. Organic farmers feel this lack of interest and the risk of not selling the food they produce.
- More time-consuming work: Organic production requires more labour, especially in terms of crop protection and cultivation. The time-consuming nature of such work may discourage potential new farmers from switching to organic farming methods.

Conventional farmers also pointed to a number of barriers that keep them from implementing an organic mode of production. Among the most frequently mentioned of these were:

- Lower yields: Conventional farmers point to lower yields in organic production compared to intensive conventional agriculture. Yield loss is one of the key factors inhibiting the decision to switch to organic production methods.
- Bureaucracy and administrative burden: The requirements for organic certification are seen as overly complicated and burdensome. Conventional farmers are concerned about the additional bureaucracy and associated costs.
- Low demand and low market: Farmers fear that the market for organic products is too small, which could prevent them from generating satisfactory revenues. As organic products are more expensive, they are only available to a narrow group of consumers, which creates uncertainty about their profitability.
- Labour shortage: Organic production requires more manual labour, which can be a problem given the difficulty of accessing labour in rural areas.
- Poor promotion of organic products: Conventional farmers believe that organic products are not promoted enough, which reduces consumer interest. Poor advertising and low availability of information on organic food also affect their perception of the market.

The responses collected show clear discrepancies in the perception of problems between organic and conventional farmers. Organic farmers emphasize problems related to operational and market difficulties, such as high costs, low productivity and limited demand for organic products. Conventional farmers, in contrast, are concerned about financial risks and difficulties related to bureaucracy and market access.

Table 7.*Biggest problems of organic farming according to farmers' opinions*

Group of farmers	
organic	conventional
low public awareness	lower yields
fear of scrutiny	I don't know
low crop yields	nope
high production costs	bureaucracy
low demand for organic products due to high prices for "premium" products	lack of quick and convenient access to purchase certified organic products
more time-consuming nature of the work performed	low demand for premium products
	small market
	shortage of labour
	low profitability
	major restrictions introduced by the EU
	high prices for organic products relative to others
	little interest in more expensive products
	poor advertising of organic products
	poor access to information about organic food production and predicting the cost of organic foods
	the price of organic products is too low, organic production is not profitable
	too much crop diversification and matching good crops to soil requirements

Source: own research.

The results of the survey indicate the need for further research into the barriers to implementing organic farming. It is worth analysing why conventional farmers, despite being aware of the benefits of organic production, do not make the decision to switch to this form of farming. It is also important to identify effective strategies that could help farmers overcome current barriers.

In conclusion, the development of organic agriculture requires integrated measures including both education, financial support and administrative changes. Eliminating or reducing the identified barriers can contribute to wider implementation of organic production methods, which in turn will benefit both farmers, consumers and the environment.

5. Conclusions

The results suggest that organic farming may be more profitable and attract farmers with higher levels of education. Nevertheless, further support from both government institutions and EU programmes is needed to fully realize the sector's potential, especially in regions such as Małopolska.

Farmers participating in the survey pointed to numerous problems in the development of organic farming, mainly in the area of market and agricultural policy. Among the most important of these are the lack of a long-term strategy to promote organic farming production,

the lack of a strong negotiating position for farmers on the market, increasing bureaucracy and administrative burdens and, most importantly, difficulties in selling products. The findings suggest that legislative institutions and organizations responsible for organic agriculture certification should take steps to simplify or reduce procedural burdens. In order to reduce supply-side barriers, it is recommended to support initiatives to bring together organic farmers, which can strengthen their position in food supply chains and lead to the shortening of these chains by selling products on local markets. The role of such activities is gaining importance in the eyes of consumers, who increasingly appreciate the benefits of a balanced diet. Consequently, the sustainable development of organic agriculture should be linked to initiatives to raise consumer awareness of the benefits of organic food.

Based on the research and analysis carried out, it can be concluded that the hypothesis assuming that organic farmers better evaluate their economic situation has been positively verified. Organic farmers show a higher level of satisfaction with their financial situation compared to conventional farmers. The research objectives of identifying motivations and barriers of an economic and social nature related to the implementation of organic certification were also realized. The research confirmed that organic farmers are more satisfied with their economic situation. This is related to both the higher prices they can get for their products and access to markets that value organic products. This satisfaction can also be attributed to the feeling that they are contributing to the protection of the environment and the production of healthy and high-quality food. Organic farmers tend to be better educated, which translates into a greater willingness to engage in innovative activities, including non-agricultural activities. They are more open to developing alternative sources of income, which improves their overall economic situation. The key motivations of organic farmers are the desire to produce healthy, high-quality food and to obtain better prices for their products. These values are well understood by conventional farmers as well, which raises the question of why they choose not to switch to organic farming despite this knowledge. The biggest barriers to implementing organic farming identified among conventional farmers are concerns about lack of markets and low profitability. Although these farmers recognize the financial benefits of organic farming, at the same time they fear the risks associated with market instability, which introduces contradictory statements. Measures to support the development of organic farming should focus on financial and marketing aspects. It is necessary to provide financial support to farmers, especially during the transition period, and to promote organic products to ensure stable markets.

Although conventional farmers are aware of the health and financial benefits of organic production, their hesitation to implement organic certification requires further research. The key questions are: why are conventional farmers reluctant to make the decision to switch to organic farming, despite being aware of the benefits?

Information campaigns are needed to promote the benefits of organic farming to both farmers and consumers. Increasing public awareness of the value of organic products can help increase demand and develop the market. It is necessary to simplify and clarify the procedures

involved in implementing organic certification. Farmers should receive clear information about the requirements and benefits of switching to organic farming, which can reduce their concerns. It is recommended that a system of subsidies and preferential loans be introduced for organic farmers in order to remove the financial barriers associated with the transition to organic production. Also, marketing of organic products should be supported by campaigns at the national and European levels. A key element of the strategy should be to improve the economic situation of farmers by giving them access to the growing market for organic products. Training and consulting programmes should also be introduced to help conventional farmers convert their farms to organic production, while minimizing economic risks.

Implementation of the above recommendations can increase the share of organic farming in the structure of agricultural production in the European Union, while improving the economic situation of farmers and promoting sustainable development.

Within the framework of agricultural policy, it is necessary to improve the efficiency of institutions and regulations, and to create a long-term strategy for the development of organic agriculture. The results of the research can serve as a basis for developing more effective policies to support the development of organic agriculture, which will be implemented by the relevant public authorities.

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EMOTIONAL EATING: FROM MEASUREMENT TOOLS TO METHODOLOGICAL DECISIONS

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Purpose: Emotional eating, understood as eating in response to emotional states rather than physiological hunger, has been widely examined across psychology, public health, and behavioral sciences. Its relevance increased during the COVID-19 pandemic, when social and economic stressors significantly altered dietary patterns, underscoring the need for precise, comparable measurement tools. The purpose of this paper is to review and compare instruments for assessing emotional eating, systematize existing measurement approaches, and support researchers in selecting scales aligned with specific research objectives.

Design/methodology/approach: A two-stage literature review was conducted. In the first stage, instruments for measuring emotional eating were identified using predefined keywords in scientific databases. In the second stage, only tools that directly measured the emotional components of eating behavior were included. The selected scales were analyzed with respect to their theoretical foundations, assessed emotional dimensions, number of items, application contexts, and availability of cultural adaptations. Based on this analysis, a decision tree was developed to guide the selection of measurement instruments.

Findings: The review demonstrates considerable heterogeneity among emotional eating scales in terms of conceptual assumptions, emotional scope, and practical applicability. Instruments differ substantially in the types of emotions assessed, methodological focus, and suitability for specific research contexts. The decision tree integrates these differences into a structured framework, facilitating informed methodological choices.

Originality/value: This paper provides a comprehensive methodological synthesis of measurement tools for emotional eating and introduces a novel decision tree to support scale selection. The study adds value by addressing a critical gap in comparability and methodological transparency in emotional eating research, targeting researchers in psychology, public health, and behavioral sciences.

Keywords: emotional eating, eating behaviors, measurement tools, review of research instruments, decision tree.

Category of the paper: Literature review.

1. Introduction

Eating behaviors, including their psychological determinants, have been the subject of interest for researchers in fields such as public health, consumer behavior, the psychology of eating, and eating disorders. A crucial area of this research is emotional eating—a form of eating behavior in which food consumption occurs in response to emotions rather than physiological hunger (Arnow et al., 1995; Bourdier et al., 2017). A significant increase in interest in this phenomenon was observed during the COVID-19 pandemic, when lifestyle changes, stress, social isolation, and economic uncertainty contributed to more frequent eating in response to emotions such as sadness, anxiety, or boredom (Barcın-Güzeldere, Devrim-Lanpir, 2022; Cecchetto et al., 2021; Di Crosta et al., 2021; Di Renzo et al., 2020). Emotional eating triggered by pandemic-related stressors has become not only a topic of numerous psychological studies but has also attracted the attention of economists, who analyze its implications for consumption, spending patterns, and purchasing decisions (Cai et al., 2024; Franklin et al., 2023; Khoshghadam, Rajabi, 2024).

Emotional eating is understood both as an emotion regulation strategy and as a response to diverse stimuli, often leading to maladaptive eating patterns. This phenomenon is associated with an increased risk of overweight, obesity, and eating disorders such as binge eating and bulimia (Frayn, Knäuper, 2018; Nolan et al., 2010). At the same time, research indicates that emotional eating is not limited to individuals with eating disorders. It also occurs in general populations and may vary in intensity depending on cultural context, gender, or life stage (Bozkurt et al., 2024; Frayn, Knäuper, 2018). Increasingly, it has also been examined by economists and market researchers who investigate its effects on consumer decision-making, impulsivity, product category management, and the broader consequences for public health and the economy.

In this context, there is a growing need for precise and reliable tools to measure emotional eating, both in scientific research and in clinical practice. Numerous measurement instruments have been developed to assess the emotional aspects of eating. Among these are scales focused exclusively on emotional eating (e.g., Emotional Eating Scale, EES), as well as scales capturing a broader spectrum of emotional eating behaviors (e.g., Three Factor Eating Questionnaire, TFEQ). Although each of these instruments was developed to address specific research needs, their abundance and partial overlap often create uncertainty and difficulties in selecting the most appropriate tool. For researchers, choosing the proper measurement instrument remains a challenge, as these scales differ in theoretical foundation, the scope of emotions included, their valence, and methods of assessment. As a result, researchers may unintentionally employ tools that are not fully aligned with the theoretical assumptions of their projects, leading not only to reduced measurement validity but also to problematic interpretation of results.

Despite the growing importance of this topic, in the fields of economics, management, and quality sciences, there is still a lack of in-depth methodological studies that would facilitate the selection of appropriate measurement scales. Researchers in these disciplines often rely on tools developed within psychological or medical literature; however, without a comprehensive guide, it is difficult to determine which scales are valid in the context of research objectives focused on consumer decision-making or emotions accompanying consumption. Methodological literature has repeatedly emphasized the need for systematic and methodological supporting tools that assist in the process of selecting measurement instruments in a logical, transparent, and theory-driven manner (DeVellis, 2016). Such tools serve an analogous function: they guide the user step by step through key questions concerning the scope, structure, and content of the instrument until the most suitable solution for a specific research problem is identified. A similar approach has been applied, for example, in reviews of instruments measuring physical activity in adolescents (Sallis et al., 2000), parental self-efficacy (Alderfer et al., 2008), or health decision-making (Shields et al., 2016), where authors organize available scales according to logical criteria (e.g., scope, target age group, cognitive vs. emotional dimension) and create guides that support instrument selection. Such solutions help avoid methodological errors and enhance the transparency of research procedures.

The aim of this article is therefore to review selected measurement tools for eating behaviors, with particular emphasis on scales directly addressing emotional eating. The presented review includes nine scales and compares their theoretical framework, type of emotions measured, number of items, contexts of application, and availability of cultural adaptations. In addition, the study is based on a systematic, expert-based reconstruction of the actual content of emotional eating subscales and individual measurement items, which allows for a more fine-grained analysis than approaches limited to declared scale characteristics. On this basis, a structured classification of constructs was developed, together with a practical decision tree for selecting emotional eating measurement scales, designed to support a more transparent and theory-consistent choice of instruments. In this way, the article seeks to complement existing reviews by offering methodological guidance that may be particularly useful to researchers in economics, management, and consumer behavior.

2. The nature of emotional eating and its measurement

Emotional eating is a term used to describe the tendency to eat in response to emotions and constitutes one of the key subscales within the broader category of emotion-related eating behavior. Within this category, alongside emotional eating, other manifestations such as binge eating are also included (Sultson, Akkermann, 2019; Tuluhong, Han, 2023). Emotional eating is defined as the tendency to consume food in response to emotions rather than physiological

hunger (Nolan et al., 2010). Initially, this concept was developed mainly in the context of negative emotions—such as sadness, anger, or anxiety—and was understood as a strategy for suppressing unpleasant emotional states. Food was assumed to serve as a mechanism of rapid emotional regulation, providing immediate but short-lived relief (Macht, 2008; Wallis, Hetherington, 2009). However, subsequent studies have also highlighted the role of positive emotions (e.g., joy, excitement), which may lead to increased food intake (Bourdier et al., 2017; Martins et al., 2023). Nevertheless, eating triggered by positive emotions is generally considered less harmful in the context of weight control than eating in response to stress or sadness. For this reason, negative emotional states (anxiety, anger, boredom, depression) have traditionally remained the primary focus of research on emotional eating (Manzoni et al., 2008). Chawner and Filippetti (2024) further note that emotions may lead either to overeating or appetite suppression. According to the authors, these behaviors are likely based on different psychological (e.g., type and intensity of emotion) and physiological mechanisms, and their occurrence depends on individual predispositions and situational context. Emotional eating can thus serve both adaptive functions (e.g., deliberately eating to improve mood) and maladaptive ones (e.g., impulsive overeating in response to stress) (Macht, 2008). Moreover, Nolan et al. (2010) emphasize that not only the type of emotion, but also everyday life situations may trigger emotional states that activate the mechanism of emotional eating.

Emotional eating can be conceptualized either as an independent phenomenon or as one component of broader models of eating behaviors, in which it is treated as one of several complementary dimensions regulating food intake. This extended perspective highlights the importance of emotional eating as part of wider eating behavior structures, rather than merely an isolated habit.

Emotional eating is a subscale of significant importance in both population-based and clinical studies. It is a measurable phenomenon associated with body weight, risk of eating disorders, and the tendency to consume energy-dense foods in an uncontrolled manner (Bourdier et al., 2017; Bozkurt et al., 2024). Its presence has been demonstrated across various groups, including the general population, individuals with overweight and obesity, as well as those with eating disorders and depressive symptoms (Frayn, Knäuper, 2018; Nolan et al., 2010; Skolmowska et al., 2023). In many cases, emotional eating is perceived as a maladaptive coping strategy, consisting of food consumption in response to difficult emotional states. Such behavior may lead to the development of uncontrolled eating patterns, an increased risk of food addiction, weight gain, and adverse health consequences (Bozkurt et al., 2024; Ljubičić et al., 2023).

As indicated above, both emotion-related eating behaviors and emotional eating itself have significant practical implications, which highlights the need to account for them in clinical practice and in the prevention of psychophysical health issues (Frayn, Knäuper, 2018; Nolan et al., 2010). At the same time, it is increasingly recognized that emotional eating extends beyond psychological issues and fits within the broader framework of purchasing behaviors and

decisions made under the influence of emotions—an area explored in economics, particularly behavioral economics. The underlying assumption is that emotions constitute a key determinant of purchasing decisions and strongly influence consumer behavior (Kahneman, 2024; Thaler, Sunstein, 2009). Consequently, emotional eating represents a complex, interdisciplinary phenomenon, the analysis of which requires consideration not only of psychological but also economic mechanisms.

In response to the growing interest in the determinants of eating behaviors, including emotional eating, numerous tools (scales) have been developed to measure them. These scales differ in terms of their theoretical assumptions, the number and type of included items, and the scope of assessment. Some of them focus on a broad spectrum of eating behaviors, while others are oriented explicitly toward selected subscales, such as emotional eating, which is the focus of the present analysis.

An additional conceptual challenge in the measurement of emotional eating concerns the distinction between emotional states and situational triggers that may evoke them. In some measurement instruments, situational contexts are implicitly treated as proxies for emotions, which may lead to a partial conflation of situational antecedents and emotional responses and, consequently, affect construct clarity and interpretation. From a consumer behavior perspective, this overlap is particularly relevant, as emotions often operate as mediating mechanisms between situational stimuli and consumption-related decisions (see Macht, 2008; Nolan et al., 2010; Kahneman, 2024).

The selection of instruments for measuring emotional eating poses a significant methodological challenge for researchers investigating eating behaviors. Although many available scales demonstrate high reliability and validity, they differ substantially in theoretical foundation, the range of emotions assessed, the number of items, response formats, and the availability of linguistic versions and cultural adaptations. An additional challenge lies in distinguishing between instruments that conceptualize emotional eating as the primary construct and those that treat it as a subscale within a broader assessment of eating behaviors. It is also important to note that not all tools differentiate between positive and negative emotions—a factor that may be crucial in studies where emotional context is considered as a moderating or mediating variable.

3. Methodology

To identify instruments used for measuring emotional eating, a literature review was conducted in the Scopus and Web of Science databases. The search process followed a two-stage procedure and was based on the analysis of publication abstracts. In the first stage, a set of key phrases was applied, divided into two thematic groups. The first group referred to

emotional eating behaviors as a phenomenon and included the terms: emotional eating, emotions & eating, emotional-related eating, emotional eating behavior, and emotional behavior. The second group referred to measurement instruments and included the terms: scale, questionnaire, and measure. These phrases were used in search queries covering publication titles, abstracts, and keywords. The aim of this stage was to obtain a general overview of the scientific literature on the relationship between emotions and eating, as well as to identify measurement tools employed in this area. An abstract screening procedure was then performed, during which recurring names of scales were extracted, both in their complete form and abbreviations (e.g., “Emotional Eating Scale”, “EES”). Based on this, a preliminary list of 13 instruments potentially related to the measurement of emotion-related eating behaviors was compiled. In the second stage, each of these scales was re-entered into the databases as a separate search query (using both the full name and abbreviation), followed by another round of abstract screening. The purpose of this stage was to verify whether a given scale was indeed designed to measure eating behaviors associated with emotions—that is, whether it contained an emotional component in its structure—or whether it had only been mentioned contextually or mistakenly in the literature.

Ultimately, nine scales directly addressing emotional eating as a subscale were qualified for further analysis. Among them are instruments specifically designed to measure this phenomenon: the Emotional Eater Questionnaire (EEQ), Emotional Eating Scale (EES), Emotional Appetite Questionnaire (EMAQ), and the Emotional Overeating Questionnaire (EOQ). In addition, several multidimensional scales that include subscales on emotional eating alongside other aspects of eating behavior were identified: the Three Factor Eating Questionnaire (TFEQ), Adult Eating Behaviour Questionnaire (AEBQ), Dutch Emotional Eating Questionnaire (DEEQ), Weight-Related Eating Questionnaire (WREQ), and the Mindful Eating Questionnaire (MEQ).

Conversely, four instruments were deliberately excluded from further analysis: the Binge Eating Scale (BES), Eating Disorder Examination Questionnaire (EDE-Q), Intuitive Eating Scale (IES), and the Yale Food Addiction Scale (YFAS). Although these scales appear in the literature on eating disorders and impulsive eating, they do not contain a component directly referring to emotional eating. Including them in the analysis would risk unjustifiably broadening the scope of this study beyond its primary objective, which is the classification of instruments specifically measuring emotional eating.

During the analysis of the empirical material, it became evident that some of the research instruments included not only the dimension of emotional eating but also a range of subscales addressing other aspects of eating behavior regulation. This created the need to systematize them so that results could be interpreted in a comprehensive and comparable manner across different questionnaires. To develop a classification of these additional subscales that do not directly address the emotional eating dimension, all constructs present in the selected instruments (e.g., TFEQ, DEBQ, WREQ, AEBQ, MEQ) were identified and aligned with their

corresponding measurement items. This approach made it possible to capture not only the subscale names but also their actual content scope. Subsequently, a comparative analysis was conducted at the level of the content of individual items and subscales. This process had an expert-based character, aiming to identify similarities and differences in what the specific items measure or reflect regarding eating behaviors and attitudes. During this stage, elements related to similar mechanisms were grouped together, such as physiological signals of hunger and satiety, responses to external stimuli, or restrictive strategies.

The next step was synthesis—merging detailed constructs and items into broader, coherent overarching categories that organize them in a structured way. The final classification was achieved through an iterative process of adjustment, in which the initial groups were verified and refined to reflect both the meaning of the items and the broader psychological context they referred to.

This procedure enabled the development of a structured overview of nine scales measuring emotional eating (Table 1), which had previously been characterized in terms of their theoretical framework, application scope, and suitability for specific populations and respondent groups. A subsequent classification included the presence of additional subscales extending beyond the emotional eating dimension (Table 2). The outcome was the development of a decision tree (Figure 1), which transparently classifies the instruments used for measuring emotional eating. This tree serves not only as a valuable methodological tool but also as a foundation for designing complex research models that incorporate multidimensional aspects of eating behaviors.

4. Emotional eating – comparative analysis of measurement instruments

Below, the nine scales included in the study are presented. Their discussion facilitates a deeper understanding of both the potential and limitations of individual instruments in scientific research as well as in practical applications.

Adult Eating Behaviour Questionnaire (AEBQ)

The AEBQ was developed by Hunot et al. (2016) based on the CEBQ (Children's Eating Behaviour Questionnaire), which was designed to assess eating behaviors in children (Wardle et al., 2001). Thus, the AEBQ represents an adaptation of the CEBQ for the adult population. It is an instrument used to assess individual appetite-related traits in adults, which may be relevant for body weight and eating patterns. The original version of the AEBQ contained 35 items forming eight subscales related to food-approach traits and food-avoidance traits: Hunger, Food Responsiveness, Emotional Overeating, Enjoyment of Food, Satiety Responsiveness, Emotional Undereating, Slowness in Eating, and Food Fussiness.

The questions addressing emotional eating referred to situations of both excessive eating and food restriction (e.g., “I eat more when I’m upset/worried/anxious/annoyed/angry; I eat less when I’m annoyed/worried/anxious/upset/angry”).

Dutch Emotional Eating Questionnaire (DEEQ)

The DEBQ is widely used in research on obesity, eating disorders, appetite control, and the influence of emotions and environmental cues on eating habits. Developed by Van Strien et al. (1986), it consists of 33 items assessing the frequency of specific behaviors: Restrained Eating—the tendency to consciously restrict food intake in order to control body weight; Emotional Eating—the tendency to eat in response to negative emotions such as sadness, stress, or anxiety; and External Eating—eating triggered by external cues (e.g., the sight or smell of food) regardless of hunger.

There is also a DEBQ-parent version, which has been shown to be a more reliable method for assessing eating behaviors in children (Braet, Van Strien, 1997). Although the original DEBQ includes 33 items, shortened versions have been used in some studies, such as DEBQ-C with 20 items (van Strien, Oosterveld, 2008) and a 16-item DEBQ (Bailly et al., 2012). The DEBQ Emotional Eating subscale consists of 13 items assessing the urge to overeat in response to negative emotions (e.g., “Do you have a desire to eat when you are irritated/nothing to do/depressed/lonely/feeling let down/cross/awaiting something unpleasant/anxious/things go against you/frightened/disappointed/upset/bored?”).

Emotional Eater Questionnaire (EEQ)

The EEQ was developed and validated by Garaulet et al. (2012) to assess emotional eating, particularly in the context of individuals with overweight and obesity. Its primary aim is to identify the extent to which emotions influence an individual’s eating habits. The questionnaire consists of 10 items concerning general eating behaviors in response to different emotional states. Only one item directly refers to three emotions (“Do you eat when you are stressed, angry, or bored?”). Responses are provided on a four-point Likert scale, where respondents indicate the frequency of specific behaviors (0 – never; 1 – sometimes; 2 – generally; 3 – always). Higher scores on the EEQ indicate stronger tendencies to eat under the influence of emotions, thus reflecting higher levels of emotional eating (0-5: non-emotional eater; 6-10: low emotional eater; 11-20: emotional eater; 21-30: very emotional eater).

Emotional Eating Scale (EES)

The original Emotional Eating Scale (EES) was developed by Arnow, Kenardy, and Agras (1995) to examine the intensity of the relationship between mood and eating among obese women. This 25-item scale used a five-point response format ranging from “no appetite” to “enormous appetite”, with intermediate values (“slight appetite”, “moderate appetite”,

and “strong appetite”). The scale included three subscales: anger/frustration (11 items), anxiety (9 items), and depression (5 items), identifying increased desire to eat in response to negative emotions.

Based on the EES, the EES-II was developed, which expanded the instrument to include positive emotions as well as both appetite suppression and appetite increase. It was assumed that some emotional states stimulate the desire to eat, while others suppress it. The EES-II included 34 items covering 23 negative and 11 positive emotions and was tested in a nonclinical sample. Mood states were identified using the Profile of Mood States (McNair, Lorr, Doppleman (1971). POMS Manual for the Profile of Mood States. San Diego, CA Educational and Industrial Testing Service. - References - Scientific Research Publishing, n.d.), which explains the different number of emotions. Similar to the original EES, the items were grouped into three subscales—depression, anxiety, and anger—with an additional fourth subscale for positive mood. The structure of emotions in EES-II was as follows:

- Depression: lonely, blue, sad, bored, inadequate, helpless, guilty, upset, frustrated, discouraged, worried, confused.
- Anger: furious, angry, irritated, resentful, on edge, rebellious.
- Anxiety: jittery, shaky, worn out, nervous, uneasy.
- Positive mood: happy, enthusiastic, pleased, alive, active, strong, excited, warm-hearted, satisfied, kindly, elated.

Further modifications of the scale include the Emotional Eating Scale for Children (EES-C), designed for use in children and adolescents (Tanofsky-Kraff et al., 2007).

Emotional Appetite Questionnaire (EMAQ)

The EMAQ, developed by Nolan, Halperin, and Geliebter (2010), assesses the tendency to increase or decrease food intake under specific emotional states and social situations. It consists of 22 items divided into four subscales corresponding to two dimensions of emotions (positive vs. negative) and two types of contexts (emotional vs. situational). Respondents rate how their appetite changes in response to the listed emotions and situations:

- Negative emotions include: sad, bored, angry, anxious, frustrated, tired, depressed, frightened, lonely.
- Positive emotions include: confident, happy, relaxed, playful, enthusiastic.
- Examples of positive situations are: when falling in love, when engaged in an enjoyable hobby, and after receiving good news.
- Negative situations include: under pressure, after a heated argument, after a tragedy of someone close to you, after ending a relationship, after losing money or property.

The EMAQ thus makes it possible to distinguish emotional eating patterns depending on both the valence of emotions (positive vs. negative) and the nature of the stimuli (emotions vs. social situations).

Emotional Overeating Questionnaire (EOQ)

The EOQ, developed by Masheb et al. (2006), measures the frequency of overeating in response to emotions, specifically assessing how many episodes of overeating participants reported during the past 28 days. Respondents evaluate the frequency of overeating triggered by five negative emotions and one positive emotion: anxiety, sadness, loneliness, tiredness, anger, and happiness. Responses are summed to determine the emotional overeating score, with higher scores indicating more frequent overeating under the influence of emotions. Scores range from 0 to 46, with values above 17 considered indicative of moderate to severe overeating and thus associated with an increased risk of eating disorders. The EOQ has been used, for example, to assess changes in eating behaviors under social isolation during the COVID-19 crisis (Constant et al., 2023). Its advantage lies in its brevity (6 items), which minimizes cognitive burden for respondents. A modified version, EOQ-5, excludes the positive emotion item (Casu et al., 2020).

Mindful Eating Questionnaire (MEQ)

The MEQ, designed by Framson et al. (2009), measures the level of mindful eating, defined as the practice of being fully present during eating, paying attention to sensory experiences such as taste, texture, and smell, as well as to internal hunger and satiety signals. Respondents evaluate their experiences of mindful eating using a four-point scale (1 = never/rarely, 4 = always/usually), with higher scores reflecting greater mindfulness in eating behaviors. The 28 items of the MEQ are grouped into five constructs: Disinhibition, Awareness, External Cues, Emotional Response, and Distraction. The Emotional Response construct includes items such as: “When I’m sad I eat to feel better”, “When I’m feeling stressed at work I’ll go find something to eat”, “I have trouble not eating ice cream, cookies, or chips if they’re around the house”, “I snack without noticing that I am eating”.

Shortened versions include the MEQ-20 (Clementi et al., 2017) and the MEQ-C for children (Hart et al., 2018).

Three Factor Eating Questionnaire (TFEQ)

The TFEQ was developed by Stunkard and Messick (1985) to measure three main aspects of eating behaviors: Cognitive Restraint (conscious restriction of food intake to control body weight), Disinhibition (tendency to overeat in response to emotional or situational cues), and Hunger (susceptibility to feelings of hunger and their influence on eating behavior). The original TFEQ included 51 items, later shortened to an 18-item version by Karlsson et al. (2000), which renamed the constructs slightly and explicitly included Emotional Eating as a subscale. In this version, emotional eating is assessed with three items: “When I feel anxious,

I find myself eating”; “When I feel blue, I often overeat”; “When I feel lonely, I console myself by eating”.

An extended 21-item version (TFEQ-R21) was developed by Tholin et al. (2005). Modified versions have also been designed for children, such as the CTFEQ-R17 and CTFEQ-R21. The TFEQ is widely used in research on obesity, weight control, and eating disorders.

Weight-Related Eating Questionnaire (WREQ)

The WREQ, developed by Schembre, Greene, and Melanson (2009) was designed to assess eating behaviors related to weight control. It identifies patterns that may influence the balance between food intake and the body’s needs, which is relevant in both weight reduction and weight maintenance contexts. The 16-item scale is organized into four subscales: Routine Restraint (everyday restriction of food intake), Compensatory Restraint (restricting intake following episodes of overeating), External Eating (eating triggered by environmental cues such as sight or smell of food), and Emotional Eating (eating as a coping mechanism for negative emotions such as stress, sadness, or tension).

The Emotional Eating subscale includes items such as: “I eat more when I’m having relationship problems”; “I tend to eat when I am disappointed or feel let down”; “When I’m under a lot of stress, I eat more than I usually do”. Several adaptations of the WREQ exist, including versions tailored to specific populations, such as pregnant women (Yeh et al., 2024), children (WREQ-C), and ethnic groups (Schembre, Geller, 2011).

The scales described above are most used by researchers in clinical psychology, psychiatry, dietetics, and public health, where emotional eating is analyzed in the context of eating disorders, overweight, addictions, or coping strategies. However, there is a growing recognition of the need to integrate these tools into research conducted within economics and management sciences, particularly in studies on consumer behavior, well-being, purchasing decisions, and relationships with food brands.

Table 1.
Comparison of emotional eating scales: psychometric and practical aspects

Scale Authors	Theoretical construct (number of items)	Emotion valence	Scale format	Reliability	Language and cultural adaptation
AEBQ Hunot, Fildes, Crocker, Llewellyn, Wardle, Beeken (2016)	Measurement of eight traits grouped into two subscales (35 items), each linked to specific eating responses: – food approach: Hunger (H, 5 – usually excluded), Food Responsiveness (FR, 4), Emotional Over-Eating (EOE, 5), Enjoyment of Food (EF, 3) – food avoidance: Satiety Responsiveness (SR, 4), Emotional Under-Eating (EUE, 5), Food Fussiness (FF, 5), Slowness in Eating (SE, 4)	Negative	5-point Likert scale from <i>strongly disagree</i> to agree strongly	0.70+	Examples: French (Canada) (Jacob et al., 2022), Italian (Gritti et al., 2024), Arabic (Alruwaitaa et al., 2022), Turkish (Yardımcı et al., 2023), Spanish (Mexico) (Hunot-Alexander et al., 2022)
DEBQ van Strien et al. (1986)	Measurement based on three subscales (33 items): – Restrained Eating (10): conscious restriction of intake to control body weight – Emotional Eating (13): eating in response to negative emotions (anxiety, anger, sadness) – External Eating (10): eating triggered by external cues such as smell or sight of food	Negative	5-point Likert scale from <i>never</i> to <i>very often</i>	0.80-0.94	Examples: French (Brunault et al., 2015), Brazilian (Almeida, 2017), Italian (Dakanalis et al., 2013), German (Nagl et al., 2016)
EEQ Garaulet et.al. (2012)	Measurement based on three subscales (10 items): – Disinhibition (6): loss of control over eating in response to emotions – Type of Food (2): preferences for specific foods in emotional situations – Guilt (2): negative feelings after emotional eating episodes Does not measure single emotions directly, but refers generally to negative affect and emotional stress	Positive & negative	4-point Likert scale from <i>never</i> to <i>always</i>	0,61-0,77	Examples: Romanian (Putnoky et al., 2023), Spanish (Bernabéu et al., 2020)
EES Arnold, Kenardy, Agras, (1995)	Measurement of the tendency to eat in response to negative emotions (25 items): – Anger/Frustration (11) – Anxiety (9) – Depression (5)	Negative	5-point Likert scale from <i>no desire to eat</i> to <i>an overwhelming urge to eat</i>	0,87-0,91	Examples: Arabic (Lebanon) (Rahme et al., 2021), Turkish (Bektas et al., 2016), Greek (Kalogiratou et al., 2019)
EMAQ Geliebter, Aversa (2003)	Measurement of tendencies (22 items) to eat in response to: – Emotions (14) – Situations (8). Assumption: different emotions and situations may increase or decrease appetite depending on their nature	Positive & negative	9-point Likert scale from <i>much less</i> to <i>much more</i>	0.81-0.87	Examples: French (Bourdier et al., 2017), Portuguese (Martins et al., 2023), Turkish (Demirel et al., 2014)

Cont. table 1.

EOQ Masheb, Grilo (2006)	Measurement of the frequency of overeating episodes triggered by emotions (6 items). Focus on assessing how often individuals consume excessive amounts in response to specific emotions	Negative + 1 positive	7-point frequency scale (number of days), from <i>no days</i> to <i>every day</i>	0.88-0.89	Italian (Casu et al., 2020)
MEQ Framson et al. (2009)	Measurement of mindful eating based on five subscales (28 items): – Disinhibition (8) – Awareness (7) – External Cues (6) – Emotional Response (4) – Distraction (3)	Negative	4-point Likert scale from <i>never/rarely</i> to <i>usually/always</i>	0.70-0.85	Examples: Chinese (Zhang et al., 2022), Brazilian (Rodrigues et al., 2024), Romanian (Serban et al., 2022), Malaysian (Abdul Basir et al., 2021), Persian (Rezaei & Jahanbin, 2022), Turkish (Kaya et al., 2022)
TFEQ-R18* Karlsson et al. (2000)	Measurement of eating behaviors based on three subscales (18 items): – Emotional Eating (3): tendency to eat in response to negative emotions – Uncontrolled Eating (9): eating in response to external cues – Cognitive Restraint (5): extent to which individuals consciously restrict food intake to control or reduce body weight + 1 item on perceived self-restraint	Negative	4-point Likert scale from <i>definitely true</i> to <i>definitely false</i>	0.70-0.90	Examples: Polish (Brytek-Matera et al., 2017; Dzielska et al., 2009), Persian (Mostafavi et al., 2017), Arabic (Alhebshi et al., 2023), Greek (Kavazidou et al., 2012), Malaysian (Rosnah, 2013), Canadian (Yabsley et al., 2019), Taiwanese (Lin et al., 2021), Italian (Rossi et al., 2024), Hungarian (Szakály et al., 2020), Mexican (Vázquez-Velázquez et al., 2022), Turkish (Karakus et al., 2016)
WREQ Schembre, Greene, Melanson (2009)	Measurement of eating behaviors based on four subscales (16 items): – Routine Restraint (3): consistent restriction of intake to control body weight – Compensatory Restraint (3): restriction after overeating or weight gain – Susceptibility to External Cues (5): tendency to eat in response to external stimuli – Emotional Eating (5): eating in response to negative emotions	Negative	5-point Likert scale from <i>not at all</i> to <i>completely</i>	0.80+	Chinese (Ho et al., 2022)

Source: author's own work based on the literature.

A comparative overview of the scales used to measure emotional eating and emotion-related eating behaviors reveals considerable diversity in both theoretical constructs and practical applications. Among them, some scales focus exclusively on measuring emotional eating (e.g., EMAQ, EEQ, EOQ), although they differ in terms of the range of emotions assessed, the number of items, and the response scale applied. Their design most often considers only negative emotions, although the EMAQ, for instance, assesses both negative and positive emotions. Another category consists of scales with a broader measurement scope, such as AEBQ, DEBQ, TFEQ-R18, or WREQ, which include emotional eating subscales but also account for other aspects of eating behavior. There are also intermediate tools whose theoretical framework is not directly centered on emotional eating but incorporates elements related to it. An example is the MEQ, which measures mindful eating but includes an emotional component.

The scales also differ in terms of the number and structure of subscales (ranging from the unidimensional EOQ to the eight-subscale AEBQ) and the total number of items, which varies from as few as 6 to more than 50, thus allowing for different levels of measurement detail. In terms of response formats, most employ 4- or 5-point Likert scales, although the EMAQ stands out with a 9-point scale that captures subtler variations in the intensity of emotional influences on eating. Most instruments demonstrate high reliability ($\alpha > 0.80$), and many have been adapted into multiple languages and cultural contexts, which enhances their utility in international comparative research.

Table 2 presents a classification of additional subscales beyond emotional eating, included in the analyzed instruments. Some scales, such as the TFEQ and WREQ, were designed not only to assess emotional responses but also other mechanisms regulating eating behavior. Including these components is particularly valuable in studies aiming to capture the broader psychological and behavioral context of food consumption. The constructs summarized in Table 2 indicate five areas that may accompany or moderate emotional eating.

The first area concerns eating control and dietary restraint, including conscious food restriction, calorie counting, or compensatory reduction of intake—strategies aimed at regulating body weight through controlled eating behaviors. Constructs such as cognitive restraint, routine restraint, or restrained eating appear in scales such as the WREQ, DEBQ, and TFEQ.

The second area relates to susceptibility to external cues, i.e., the tendency to eat in response to environmental stimuli such as the smell or sight of food, or the presence of others eating. These constructs are measured, for example, through subscales like susceptibility to external cues or external eating, as in the WREQ and DEBQ.

The third area includes responses to hunger and satiety, capturing individual differences in perceiving physiological signals regulating eating. Indicators such as hunger, satiety responsiveness, or uncontrolled eating appear in instruments like the AEBQ and TFEQ.

The following two components are more subtle. One is eating pace, measured by subscales such as slowness in eating, which may indirectly affect satiety regulation. The other concerns attitudes and preferences toward food, such as enjoyment of food, food fussiness, or awareness—indicators that reveal individual differences in food-related affect and cognition.

The final category refers to distraction and impulsivity during eating, which may interfere with self-regulation, especially when coupled with emotions. Such components, captured for instance in the MEQ, are particularly relevant for research on automatisms and lack of mindfulness in emotional eating.

Table 2.*Categories and constructs of selected scales – examples*

Category	Constructs of individual scales	Example items
Dietary restrictions	Routine Restraint (RR) (WREQ)	- I often refuse foods or drinks offered because I am concerned about my weight. - I purposefully hold back at meals in order not to gain weight. - I count calories as a conscious means of controlling my weight.
	Compensatory Restraint (CR) (WREQ)	- When I know I'll be eating a big meal during the day, I try to make up for it by eating less before or after that meal. - If I eat more than usual during a meal, I try to make up for it at another meal. - When I have overeaten during the day, I will often eat less than usual the following day.
	Restrained Eating (DEBQ)	- I deliberately eat less than I want. - I avoid eating certain foods because I am on a diet.
	Cognitive Restraint (CR) (TFEQ)	- I consciously hold back at meals in order not to gain weight. - I do not eat some foods because they make me fat.
External stimuli	Susceptibility to External Cues (EX) (WREQ)	- Some foods taste so good I eat more even when I am no longer hungry. - When I'm offered delicious food, it's hard to resist even if I've just eaten. - If I see others eating, I have a strong desire to eat too.
	External Eating (DEBQ)	- I eat more when I see others eating. - When I see a real delicacy, I often get so hungry that I have to eat right away.
	Food Responsiveness (FR) (AEBQ)	- When I see or smell food that I like, it makes me want to eat. - I am always thinking about food.
	External Cues (MEQ)	- I recognize when food advertisements make me want to eat. - I notice when I'm eating from a dish of candy just because it's there.
Satiety & hunger	Satiety Responsiveness (SR) (AEBQ)	- I often leave food on my plate at the end of a meal. - I get full up easily.
	Hunger (H) (AEBQ)	- If I miss a meal, I get irritable. - I often feel so hungry that I have to eat something right away.
	Uncontrolled Eating (UE) (TFEQ)	- Sometimes when I start eating, I just can't seem to stop. - I am always hungry, so it is hard for me to stop eating before I finish the food on my plate.
	Disinhibition (MEQ)	- If there are leftovers that I like, I take a second helping even though I'm full. - If there's good food at a party, I'll continue eating even after I'm full.
Eating speed	Slowness in Eating (SE) (AEBQ)	- I am often last at finishing a meal. - I eat more and more slowly during the course of a meal.

Cont. table 2.

Food attitude & preferences	Enjoyment of Food (EF) (AEBQ)	- I love food. - I enjoy eating.
	Food Fussiness (FF) (AEBQ)	- I often decide that I don't like a food before tasting it. - I refuse new foods at first.
	Awareness (MEQ)	- I notice when there are subtle flavors in the foods I eat. - I taste every bite of food that I eat.
Distracted eating	Distraction (MEQ)	- My thoughts tend to wander while I am eating. - I eat so quickly that I don't taste what I'm eating.

Source: author's own work based on the literature.

The decision tree presented in Figure 1 responds to the need for developing systematic, methodological tools that support the process of selecting measurement scales in the domain of emotional eating. It accounts for the most critical distinctions between the instruments: the scope of the emotional construct (emotions vs. emotions + situations), the valence of emotions (negative emotions vs. both positive and negative emotions), the direction of consumption (eating more vs. eating less or the same and more), as well as the presence of additional components (e.g., eating control, susceptibility to external cues). This approach enables a rapid yet accurate alignment of the scale with the research objective. The application of such a tool enhances both the validity of methodological choices and the comparability of results across studies, which is of particular importance in the context of meta-analytic syntheses and the advancement of the research paradigm on emotional eating—extending beyond medical and psychological disciplines.

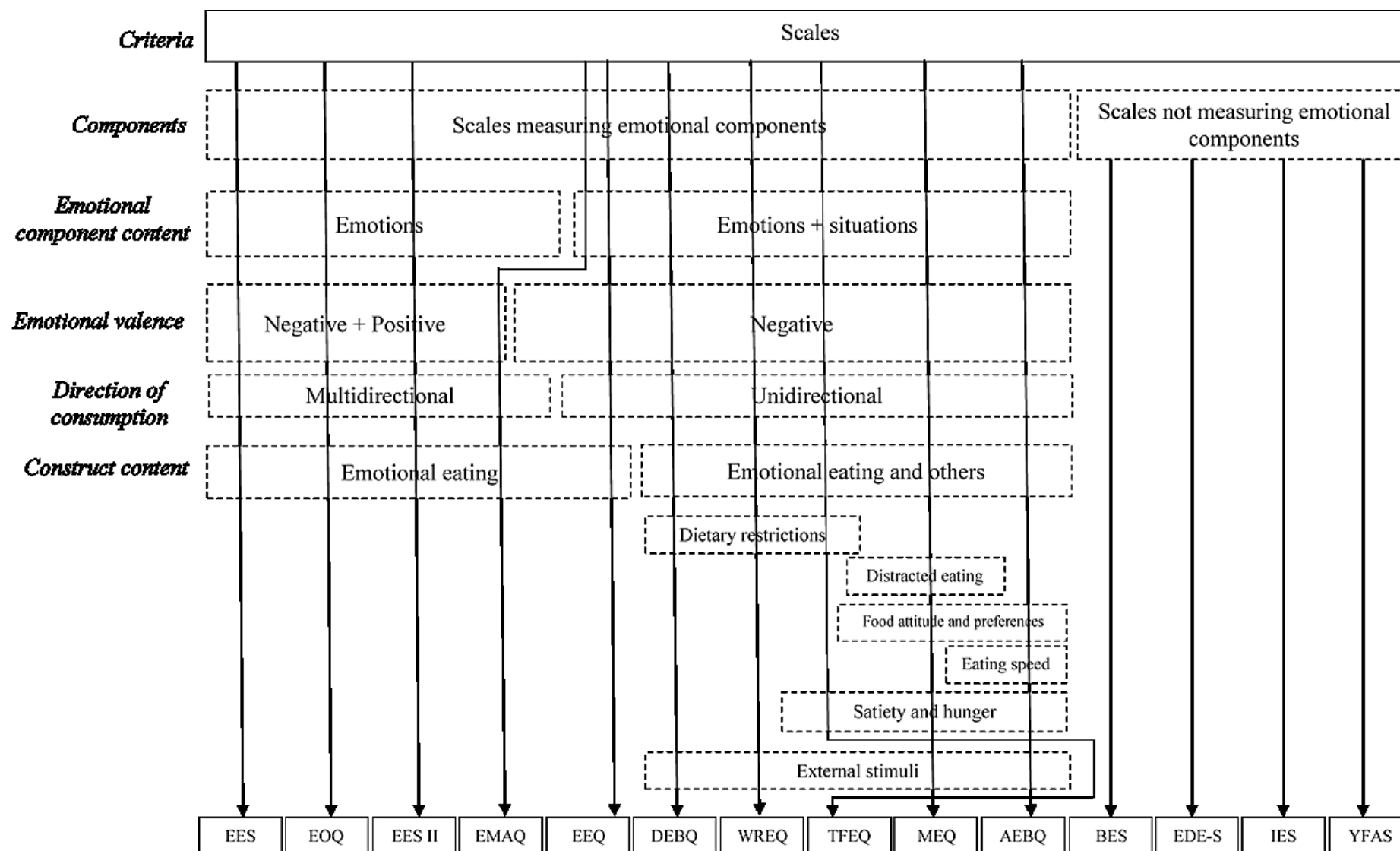


Figure 1. Decision tree for the selection of an emotional eating scale.

The logic of navigating the decision tree is based on a systematic progression through successive decision levels, starting from the most general distinction—the presence or absence of an emotional component in each scale. This initial branching serves as the starting point of the entire structure. Scales that do not include an emotional component, such as BES, EDE-Q, IES, or YFAS, are excluded from further analysis at this stage. Although these tools can provide valuable insights into eating behaviors, they do not allow for the direct assessment of the relationship between emotions and eating and are therefore not adequate for measuring emotional eating *sensu stricto*.

For scales that do include an emotional component, the structure of the tree guides the user through subsequent layers of differentiation, enabling increasingly precise alignment of the instrument with the specific research objectives. The first of these levels concerns the content of the emotional component—whether the scale measures reactions to emotions without reference to situational context, or whether it also incorporates life situations that trigger emotions. For instance, EMAQ employs items such as “When I am sad, I eat less/same/more”, directly addressing a given emotional state. Other scales, however, refer to more complex scenarios such as relationship problems or experiences of criticism, thereby broadening their application in research that considers the socio-psychological context of emotional eating.

The next level of differentiation concerns the valence of emotions, i.e., their affective direction. A key question is whether a given scale captures only negative emotions—such as sadness, anger, or frustration—or also includes positive emotions, such as joy or excitement. This distinction carries both theoretical and practical importance: scales focusing solely on negative emotions emphasize eating as a coping strategy for discomfort, while those also incorporating positive emotions allow for the identification of hedonic eating, i.e., eating that serves to sustain positive well-being.

The following step in the decision tree relates to the direction of consumption. This criterion addresses whether emotions lead to an increase in food intake, a decrease, or no change at all. While most scales assume a unidirectional effect—an increase in food intake in response to emotions—there are also instruments, such as EMAQ, that capture multiple behavioral variants by allowing respondents to indicate whether they eat less, the same, or more depending on the emotional state. This enables the identification of different regulatory strategies and individual differences in coping with emotions through eating.

The application of a decision tree in the process of selecting an appropriate measurement scale thus ensures a systematic and transparent alignment of the instrument with the specific research problem. Below, two examples are presented to illustrate how moving through successive decision criteria leads to a logical and justified selection of a particular scale.

Research Question 1: What mechanisms link compulsive buying tendencies with eating behaviors under the influence of negative emotions?

The researcher has at their disposal a tool for measuring compulsive buying (e.g., the Compulsive Buying Scale – CBS, (d'Astous et al., 1990)) and seeks to examine which shared regulatory mechanisms link compulsive buying with emotional eating. To address this research problem, the researcher begins the procedure of selecting an appropriate tool with the first distinction in the decision tree – the presence of an emotional component in the scale. At this stage, questionnaires that do not directly measure the emotional aspects of eating, such as BES, EDE-Q, IES, or YFAS, are excluded, as they do not allow for capturing the role of emotions in consumer behavior. The next step involves analyzing the scope of the emotional component. The researcher decides that they are interested not only in reactions to emotions in isolation but also in the situational context, since compulsive buying, much like emotional eating, is shaped not only by emotions themselves but also by broader social and psychological circumstances. For this reason, scales that focus solely on emotions, such as EES, are eliminated, while priority is given to instruments that encompass both emotions and situational triggers.

The following level of analysis concerns the valence of emotions. The research problem focuses on negative emotions. The next criterion is the direction of consumption. Since the research question concerns mechanisms that foster an increase in consumption, scales that only capture decreases in food intake are excluded. Finally, the presence of additional measurement components is considered. In a study aiming to connect compulsive buying with eating regulation, not only indicators of emotional eating but also constructs such as disinhibition and cognitive restraint become particularly relevant.

As a result of this systematic progression through the decision tree, the optimal choice is the Three-Factor Eating Questionnaire. This scale enables the simultaneous assessment of the impact of negative emotions, regulatory mechanisms in eating, and additional psychological factors that may constitute a shared foundation with compulsive consumer behaviors.

Research Question 2: How is consumer well-being related to the direction of changes in eating behaviors under the influence of emotions and life situations?

The researcher, equipped with the Satisfaction with Food-related Life Scale (SWFL) (Grunert et al., 2007), aims to explore how consumer well-being is connected to changes in eating behaviors triggered by emotions and life situations. To select an appropriate measurement tool, they follow the logic of the decision tree. The first distinction concerns the presence of an emotional component. Instruments lacking this dimension, such as BES, EDE-Q, IES, or YFAS, are excluded, as they do not directly assess the affective processes relevant to the study.

The next step involves the scope of the emotional component. Because the research question addresses not only emotions themselves but also the broader circumstances in which they occur, scales that measure emotions in isolation—such as the EES—are set aside. Instead, preference

is given to instruments that capture both emotional states and situational contexts, which are necessary to fully examine how well-being shapes emotional eating.

The third level of the decision process concerns the valence of emotions. Since consumer well-being reflects both positive and negative affect, the researcher opts for a tool that incorporates both. As a result, scales focusing exclusively on negative emotions are excluded.

Another important criterion is the direction of consumption. The study requires a multidirectional measure that can distinguish whether emotions and situations lead to greater food intake, reduced intake, or no change at all. Instruments that only capture increases in consumption are therefore deemed unsuitable.

Through this systematic narrowing of options, the Emotional Appetite Questionnaire (EMAQ) emerges as the most suitable instrument. It captures responses to both positive and negative emotions, incorporates situational triggers, and allows for multidirectional assessment of consumption. These features make EMAQ particularly appropriate for investigating the complex interplay between consumer well-being and emotional eating.

5. Conclusion

The review of nine scales applied in studies on emotional eating indicates substantial differences in their theoretical underpinnings and practical applications. These differences directly affect research outcomes, comparability of findings, and the validity of conclusions. Some tools focus solely on excessive food consumption (e.g., EES, EOQ), while others also capture the direction of consumption changes (e.g., EMAQ), and still others include emotional eating as part of a broader assessment of eating behaviors (e.g., DEBQ, TFEQ). A limitation of many scales is the uneven representation of emotions of different valences. Most focus exclusively on negative emotions, which may oversimplify the understanding of emotions in eating behavior. Yet, research shows that positive emotions can also trigger food intake impulses, serving as a reward or as a way of maintaining positive mood. Failure to capture this dimension may result in a measurement gap and hinder conclusions regarding emotional eating behaviors. In some scales, such as MEQ or AEBQ, the emotional component is only indirectly represented, which reduces their usefulness for studies focusing strictly on emotional eating.

To address these challenges, this article proposes a decision tree that systematizes scattered knowledge and organizes the criteria for selecting appropriate scales. Although the decision tree is not itself a measurement tool, its value lies in supporting the decision-making process of scale selection and in increasing the validity of methodological choices. The tree's structure improves navigation through this complex research domain, highlights differences between available scales, and enables researchers to align instruments more closely with their research

objectives. This approach helps minimize methodological errors resulting from inappropriate tool selection and shortens the preparation time for empirical studies.

Beyond its immediate application, the decision tree also has developmental potential. It encourages reflection on the strengths and limitations of different measurement methods and can serve as a foundation for comparative, validation, and cross-cultural studies, as well as the design of new, more comprehensive approaches to measuring eating behaviors, including emotional eating. Notably, the tool has interdisciplinary potential. It can be applied not only in psychology, dietetics, and public health but also in management and economics. Emotional eating is increasingly analyzed as an element of consumer behavior, associated with purchasing decisions, food product choices, and susceptibility to marketing communication. By pointing to appropriate measurement scales, the decision tree can help researchers better understand how emotions affect consumption, which situations intensify emotional eating tendencies, and which factors limit the rationality of consumer choices. From a behavioral economics perspective, this tool may support market research design and segmentation analyses in which emotional eating serves as a differentiating variable.

In addition to its applied value, the decision tree contributes methodologically by supporting the standardization of measurement tool selection, enhancing transparency in researchers' decisions, and improving the comparability of studies conducted across countries and cultures. Its flexible structure also allows for further development and updates as new scales, validation studies, cultural adaptations, and language versions emerge.

In conclusion, the proposed decision tree can be considered a tool of high applied and methodological value. It serves not only as a guide for selecting scales but also as a means of integrating knowledge, standardizing research practices, and inspiring the development of new approaches to studying and measuring eating behaviors. Its interdisciplinary character creates a bridge between theory and practice, as well as between medical and health sciences and the social sciences. In this sense, it represents a valuable contribution and inspiration for further research on emotional eating and for generating meaningful implications for both science and practice.

We postulate that constructs and tools for measuring emotional eating should also be incorporated into research projects aimed at designing health interventions, promoting responsible consumption, and improving consumer well-being. Integrating psychological and economic perspectives in the analysis of emotional eating may contribute to the development of more holistic models of consumer behavior, as well as to the formulation of more precise recommendations for health policies and marketing strategies. Given the growing interest in emotional eating across disciplines, the combination of psychological and economic approaches becomes not only possible but indeed necessary.

The scope of this review was restricted to two databases (Scopus and Web of Science) and to publications in English, which may have led to the omission of some relevant studies. Furthermore, although the proposed decision tree is a useful tool, it does not account for all

possible theoretical, cultural, and contextual factors that may play a role in the selection of measurement instruments.

An additional limitation of this review is its exclusive focus on self-report instruments used to measure emotional eating. Although such measures are widely applied in consumer and management research and provide insight into subjective consumption-related experiences, they may be susceptible to common-method bias and social desirability effects; therefore, future studies could benefit from combining self-report scales with behavioral or experimental approaches to enhance measurement validity.

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**FINANCIAL STANDING AND SUSTAINABLE DEVELOPMENT
OF MANUFACTURING ENTERPRISES – EVIDENCE FROM POLAND**

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Purpose: The paper aims to assess the level of dependence between financial standing and the sustainable development of manufacturing enterprises in Poland from 2008 to 2021.

Design/methodology/approach: We created synthetic indicators of sustainable development and its pillars, conducted a correlation analysis and built single- and multi-equation econometric models. We used the Ordinary Least Square (OLS) and Seemingly Unrelated Regression (SUR) methods.

Findings: The research results show that financial standing statistically impacts the sustainability of Poland's manufacturing enterprises. The practical implications we have noted are the need to maintain appropriate financial standing, which is the basis for creditworthiness and investment opportunities.

Research limitations/implications: The availability of data, the choice of normalization method and the choice of research sample.

Practical implications: The empirical implications include that the results of the analyses can support the managers of enterprises in making operational and strategic decisions.

Social implications: The issue of taking into account social development not only in strategic analyses, but also in operational ones.

Originality/value: The study's novelty is an original approach to assessing financial standing and statistical models allowing for examining the relationship between it and sustainable development.

Keywords: financial standing, sustainable development, manufacturing enterprises.

Category of the paper: Research paper.

1. Introduction

The concept of a company's financial standing can be considered an ambiguous term and, at the same time, difficult to define. The financial standing of an enterprise should be related to its financial situation (Kowalak 2020). Financial standing is the ability of an enterprise to finance current and future activities from its assets. This financing may be different and may refer to both covering the costs of living and consumable labor, as well as loan repayments, dividend payments and settlement of current liabilities by the company. It may have its source in the company's external capital.

Good financial standing is the basis for sustainable development based on three pillars: economic, social and environmental, as it enables socially and ecologically responsible activities (Gubareva et al., 2023; Esparcia, Gubareva, 2024). The ground for assessing financial standing is the index assessment of liquidity, profitability, operational efficiency, and debt.

The manuscript's novelty is its original approach to assessing the impact of financial standing on the sustainable development of manufacturing enterprises. For this purpose, we have determined synthetic indicators of financial standing (FS) and sustainable development of enterprises (SD) and its three pillars: economic (E), social (S) and environmental (Env).

We build the single- and multi-equation models and use Pearson's r , Spearman's ρ , Gamma and Kendall rank correlation coefficients, Ordinary Least Square (OLS) and the Seemingly Unrelated Regression (SUR). We checked the assumption of the methods, including unit root tests (KPSS test), homoskedasticity (White test), autocorrelation (Durbin-Watson and Breusch-Godfrey tests), normality (Doornik-Hansen test), collinearity (Variance Inflation Factor).

We focus on the manufacturing section (PKD 2007: C) due to its size, role in creating GDP and jobs, and importance for environmental protection. The research period covers the financial crisis in 2008 to the COVID-19 pandemic. We want to analyze both the financial and property situation dynamics.

The limitations of the models are the selection of analytical variables for the synthetic indicators created, the research period and the choice of model estimation methods. Moreover, the impact of FS on SD in other economic sectors may be different in terms of strength and direction of impact.

The presented model can support enterprises' decisions that respect the socio-economic development and climate aspects. Maintaining an appropriate financial and property situation should be important when creating a company's strategy.

2. An overview of the literature

2.1. Financial standing of the company

The financial standing of a company can be interpreted as the financial condition of the company (Kliestik et al., 2020). It means the overall financial condition of the company, which can be assessed on the basis of various factors such as profits, cash flow, debt, financial liquidity, profitability, etc. (Dirman, 2020). Assessment of the financial standing of a company is important both for internal management and for external stakeholders such as investors, lenders, and market analysts. Analysis of a company's financial standing usually requires the use of various indicators and methods to obtain a more complete picture of the situation (Masharipov, 2023; Blais et al., 2023). It is also important to take into account the market context and the specific nature of the industry in which the company operates (Möller et al., 2020).

Modern business management requires an accurate diagnosis of all aspects related to the environment and functioning on a given market, as well as quick making of various decisions, which sometimes have a huge impact on the future of the company, its assets, and the employees (Day, 1994; Ibeh et al., 2024; Litvaj et al., 2022). In order to rationally manage an economic entity, the Management Board must have the best possible understanding of the company's realities (including the industry in which it operates); they should also know the effects of past investments, as well as the effectiveness of the decisions made (Dong et al., 2021). An enterprise is an independent organisational unit with two main goals: survival on the market and maximisation of profits. These goals are interrelated, and their measures are solvency and profitability, respectively (Holátová et al., 2013). Lack of profits may affect financial liquidity, and, in turn, liquidity problems may reduce the ability to increase profits (Amoa-Gyarteng, 2021). Insolvency is the reason for bankruptcies of companies, which often go bankrupt even though they are profitable (Voda et al., 2021; Bolek et al., 2023). In order to make decisions that are rational for the company, the management board must be guided by its expected financial consequences (Bolek et al., 2019). Financial analysis is an extremely useful tool for assessing the above-mentioned activities.

Analysis as a research method allows you to divide the whole into individual factors, check the mechanisms of connections, and cause-and-effect relationships between the components. Financial analysis examines the dynamics and structure of elements of financial statements and the financial condition of an enterprise, mainly assessing its profitability, financial liquidity, operational efficiency, and financial structure (Hasanaj et al., 2019; Rafid et al., 2024). Enterprise analysis also allows you to effectively assess whether a given business entity is at risk of bankruptcy (Kanapickienė et al., 2023).

The results obtained using the discussed tool are used not only by the management of the business entity, but also by the owners (shareholders), who, based on the analysis, can conclude about the effectiveness of the policy and, if necessary, decide to change the management board (Shi et al., 2021; Zhou et al., 2022). The assessment of financial analysis is also useful for investors who want to invest their money in shares of a given company, contractors, and a bank granting an investment loan or an organisation subsidizing a given project - it allows to assess the direction in which the entity is heading and compare its results to the entire market, sector, or industry leader (Palepu et al., 2020; Kliestik et al., 2020; Kepramareni et al., 2023).

All decisions made in an enterprise that are used to achieve its primary goals by maintaining profitability and solvency are related to the financial sphere (Blessing et al., 2023; Fikri et al., 2023). Finance is a fundamental factor in the business management process because it provides useful tools to optimise the use of limited resources and make rational decisions. Comparability and choice between multiple, often significantly different, ventures are only possible because of their financial impact on the venture (Ibeh et al., 2024; de Zarzà et al., 2023; Ardanta et al., 2024).

Individual decisions made by the company's management can be classified into four groups, with specific financial consequences.

- operational decisions include: establishing a sales, production, and purchasing programme; establishing product margins; defining the rules for crediting recipients and repaying creditors; determining how to invest financial surpluses in the short term (Liu et al., 2024; Al-Surmi et al., 2022),
- investment decisions include investments in tangible and financial fixed assets and short-term securities, preceded by appropriate analyses (Adhikari 2020),
- financial decisions include obtaining equity capital through the issuance of shares or shares, obtaining external capital by taking out loans or credits (Nukala et al., 2021; Гринюк et al., 2023; Ahmed et al., 2024),
- dividend decisions involve the division of profit into a part that will increase equity capital or into a dividend (Sitompul et al., 2020; Tran, 2024; Leary et al., 2024).

Finance is therefore a very important factor in the effective management of an enterprise, as it enables making rational decisions and the comparability of decisions made; their effects are expressed in monetary units (Damodaran, 2024; Sitinjak et al., 2023).

2.2. Financial standing and sustainable development of manufacturing enterprises

Sustainable development is a concept that assumes harmonious economic, social, and ecological development, meeting the needs of current generations without compromising on the benefit of future generations. The term gained popularity thanks to the 1987 Brundtland Report (Brundtland, 1987), which defined sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their

own needs. Sustainability is not only a necessity, but also an opportunity to create value for businesses, society, and future generations (Hart et al., 2003). Companies that implement sustainable practices can gain a competitive advantage, improve their reputation, and contribute to a more sustainable world (Gomez-Trujillo et al., 2020; Delgado-Ceballos et al., 2023).

Sustainable development of manufacturing enterprises is a comprehensive approach that requires the integration of economic, ecological, and social aspects of activity. Companies that effectively implement sustainability strategies can achieve benefits in the form of greater operational efficiency, better access to capital, improved reputation, and increased market competitiveness (Rubio-Andrés et al., 2024; Bagh et al., 2024). In the long term, sustainable development becomes not only an obligation, but also an opportunity to build lasting value for all stakeholders. This means that companies must balance their financial goals with environmental and social responsibility (Khatib, 2024; Coelho et al., 2023; Barauskaite et al., 2021).

The financial standing of a company and sustainable development are two key aspects that can influence each other (Zhou et al., 2022). Sustainable development of manufacturing enterprises refers to conducting business activities in a way that is beneficial both to the economy, the environment, and society (Shabbir et al., 2020; Al Frijat et al., 2024). Companies that invest in environmentally friendly technologies, energy efficiency, and responsible production practices can improve their financial standing in the long term. These investments can lead to lower operating costs and reduced regulatory risks (Bhat et al., 2024; Rahi et al., 2024). Companies that demonstrate a commitment to sustainability may also have easier access to financing. Investors and financial institutions increasingly take into account ESG criteria (Environmental, Social, and Governance) when making investment decisions (Oliver Yébenes, 2024; Park et al., 2021). In addition, its strong financial standing enables the company to invest in sustainable technologies and practices (Ikram et al., 2021). Businesses in good financial condition can make long-term investments that can bring benefits in the future. Companies with a good financial situation can allocate more funds to research and development (R&D), which may lead to innovations in the area of sustainable development (Duque-Grisales et al., 2020; Adomako et al., 2024). An innovative approach to production, use of raw materials, and waste management can significantly reduce the negative impact on the environment (Mostaghimi et al., 2023). Sustainability practices can lead to greater operational efficiency, for example by reducing energy, water, and raw material consumption (Li et al., 2023; Majid et al., 2023). This, in turn, can reduce operating costs and improve profitability. Companies must develop risk management strategies that take into account financial and sustainability aspects (Alkhodary, 2023; Jasiyah et al., 2024; Fu et al., 2024).

3. Research methods

The research's primary aim is to assess the strength and direction of the impact of financial standing on the sustainable development of manufacturing enterprises in Poland from 2008 to 2021. The analysis covers the period from the financial crisis to the COVID-19 pandemic. We focus on the manufacturing section because of its contribution to GDP, employment participation and its impact on the natural environment.

We formulated the following central hypothesis:

The financial standing has a statistically significant ($p < 0.05$) and positive impact on the sustainable development of manufacturing enterprises in Poland from 2008 to 2021.

This approach results from the fact that good financial standing means a higher ability to get external financial resources, credits and loans, which allows for the implementation of socially and ecologically responsible investments.

Additionally, we formulated the following research questions:

- Which economic, social or environmental development dynamics are higher in the analyzed period?
- Did the financial crisis and then the COVID-19 pandemic affect the financial standing of manufacturing enterprises?
- Which pillar of sustainable development is most influenced by financial standing?

We conducted our research in several stages. First, we specified indicators of sustainable development of enterprises (SD) and its pillars: economic (E), social (S) and environmental (Env). We use the following procedure:

$$SD_i = E_i + S_i + Env_i = \frac{1}{n} \sum_{j=1}^n E_{ij} + \frac{1}{n} \sum_{j=1}^n S_{ij} + \frac{1}{n} \sum_{j=1}^n Env_{ij} ; (i = 1, 2, \dots, n) \quad (1)$$

where:

Sd_i – the synthetic indicator in the i -year,

n – is the number of metrics,

E_i – economic development in the i -year,

S_i – social development in the i -year,

Env_i – environmental development in the i -year.

Then, we transform the explanatory variables to unify their measuring scales using the following formulas:

- for the stimulants:

$$z_{ij} = \frac{y_{ij}}{\max_i \{y_{ij}\}}, z_{ij} \in [0; 1]; \quad (2)$$

- for the destimulants:

$$z_{ij} = \frac{\min_i \{y_{ij}\}}{y_{ij}}, z_{ij} \in [0; 1]. \quad (3)$$

where:

z_{ij} – the normalized value of the j -th variable in the i -th year,

y_{ij} – the value of the j -th variable in the i -th year,

$\min_i\{y_{ij}\}$ – the lowest value of the j -th variable in the i -th year,

$\max_i\{y_{ij}\}$ – the highest value of the j -th variable in the i -th year.

We normalized the SD and its pillars (E, S, Env) indicators based on diagnostic variables divided into stimulants and destimulants (Table 1). We assumed no collinearity between the variables and equivalent weights of the impact on SD.

Table 1.

Diagnostic variables used in the SD and its pillars (E, S, Env)

Synthetic index	Diagnostic variable	Description of the variable	Stimulant	Destimulant
Economic development (E)	y ₁	Total number of companies in a country	+	
	y ₂	Turnover or gross premiums [million PLN]	+	
	y ₃	Production value [million PLN]	+	
	y ₄	Value added at factor cost [million PLN]	+	
	y ₅	Gross operating surplus [million PLN]	+	
	y ₆	Total purchases of goods and services [million PLN]	+	
	y ₇	Gross investment in tangible goods [million PLN]	+	
	y ₈	Investment rate (investment/value added at factors cost) [%]	+	
	y ₉	Share of personnel costs in production [%]		+
	y ₁₀	Average personnel costs [thousand PLN]		+
Social development (S)	y ₁₁	Wages and Salaries [million PLN]	+	
	y ₁₂	Social security costs [million PLN]	+	
	y ₁₃	Total number of employees in a country	+	
	y ₁₄	Turnover per person employed [thousand PLN]	+	
	y ₁₅	Apparent labour productivity [thousand PLN]	+	
	y ₁₆	Gross value added per employee [thousand PLN]	+	
	y ₁₇	Growth rate of employment [%]	+	
	y ₁₈	Number of persons employed per enterprise	+	
	y ₁₉	Investment per person employed [thousands PLN]	+	
	y ₂₀	Personnel costs [million PLN]		+
Environmental development (Env)	y ₂₁	Carbon dioxide emission [tons]		+
	y ₂₂	Methane emission [tons]		+
	y ₂₃	Nitrous oxide emission [tons]		+
	y ₂₄	Sulphur oxides emission [tons]		+
	y ₂₅	Ammonia emission [tons]		+
	y ₂₆	Carbon monoxide emission [tons]		+
	y ₂₇	Nitrogen oxides emission [tons]		+
	y ₂₈	Generation of total waste [tons]		+
	y ₂₉	Generation of total waste [tons]		+
	y ₃₀	Generation of chemical waste [tons]		+
	y ₃₁	Generation of glass wastes [tons]		+
	y ₃₂	Generation of paper and cardboard wastes [tons]		+
	y ₃₃	Generation of plastic wastes [tons]		+

Source: own study on the basis of GUS database.

We calculated the FS (4) index based on the following variables:

- stimulants: current ratio (CR), quick ratio (QR), return on sales (ROS), return on assets (ROA), return on equity (ROE), total assets turnover (TAT) / Productivity of assets,
- destimulants: operating cycle (OC, in days), debt ratio (DR), long-term debt to equity (LD/E).

$$\begin{aligned}
 FS_i = & \beta_0 + \beta_1 \frac{CR_{ij}}{\max_i \{CR_{ij}\}_i} + \beta_2 \frac{QR_{ij}}{\max_i \{QR_{ij}\}_i} \\
 & + \beta_3 \frac{ROS_{ij}}{\max_i \{ROS_{ij}\}_i} + \beta_4 \frac{ROA_{ij}}{\max_i \{ROA_{ij}\}_i} + \beta_5 \frac{ROE_{ij}}{\max_i \{ROE_{ij}\}_i} \\
 & + \beta_6 \frac{TAT_{ij}}{\max_i \{TAT_{ij}\}_i} + \beta_7 \frac{\min_i \{OC_{ij}\}}{OC_{ij}_i} + \beta_8 \frac{\min_i \{DR_{ij}\}}{DR_{ij}_i} \\
 & + \beta_9 \frac{\min_i \{LD/E_{ij}\}}{LD/E_{ij}_i} \varepsilon_i
 \end{aligned} \tag{4}$$

Then, we examine the strength and direction of a linear relationship between the SD and NS (financial standing). To do this, we use Pearson's R, Spearman's Rho, Gamma Coefficient (Goodman and Kruskal's Gamma), Tau Kendall's Coefficient. We adopt the ranges of correlation strength that were suggested by Evans (2006): $|r_{xy}| = 0$ —no correlation; $0 < |r_{xy}| \leq 0.19$ —very weak; $0.20 \leq |r_{xy}| \leq 0.39$ —weak; $0.40 \leq |r_{xy}| \leq 0.59$ —moderate; $0.60 \leq |r_{xy}| \leq 0.79$ —strong; $0.80 \leq |r_{xy}| \leq 1.00$ —very strong.

In the next step, we apply a regression analysis to assess the links between SD and FS and its subindices. The simple linear regression is determined according to the formula (5):

$$SD_i = \beta_0 + \beta_1 FS_i + \beta_1 FS_{i-1} + \varepsilon_i \tag{5}$$

where:

β_0 —the intercept,

β_1 —the slope,

ε_i —denotes the i -th residual,

I —an observation index.

The estimated models are given by the equations:

$$SD = \hat{\beta}_0 + \hat{\beta}_1 FS_i + \hat{\beta}_2 FS_{i-1} + e_i = \widehat{SD}_i + e_i \tag{6}$$

so the residual for each observation is as follows:

$$e_i = SD_i - \widehat{SD}_i = SD - (\hat{\beta}_0 + \hat{\beta}_1 FS_i + \hat{\beta}_1 FS_{i-1}) \tag{7}$$

For regression analysis, we use the most common estimation method for linear models called the ordinary least squares (OLS) regression. The OLS procedure minimizes the sum of squared residuals:

$$s(\hat{\beta}_0, \hat{\beta}_1) = \sum_{i=1}^n e_i^2 = \sum_{i=1}^n (SD_i - \widehat{SD}_i)^2 = \sum_{i=1}^n (SD_i - \hat{\beta}_0 - \hat{\beta}_1 FS_i - \hat{\beta}_2 FS_{i-1})^2 \rightarrow \min \tag{8}$$

To assess the impact of FS on E, S, Env we build three equations based on the following formulas:

$$\begin{aligned} E_i &= \alpha_0 + \alpha_1 FS_i + \alpha_2 FS_{i-1} + \alpha_3 S_i + \alpha_4 Env_i + \varepsilon_i \\ S_i &= \alpha_0 + \alpha_1 FS_i + \alpha_2 FS_{i-1} + \alpha_3 E_i + \alpha_4 Env_i + \varepsilon_i \\ Env_i &= \alpha_0 + \alpha_1 FS_i + \alpha_2 FS_{i-1} + \alpha_3 E_i + \alpha_4 S_i + \varepsilon_i \end{aligned} \quad (9)$$

We use feasible generalized least squares (FGLS) to estimate the SUR model. The residuals from our regression are used to estimate the elements of matrix:

$$\hat{\sigma}_{ij} = \frac{1}{R} \hat{\varepsilon}_i^T \hat{\varepsilon}_j \quad (10)$$

Then, we run generalized least squares regression for using the variance matrix:

$$\begin{aligned} \Omega &\equiv E[(\varepsilon\varepsilon^T|X)] = \sum \Omega \otimes I_R \\ \hat{\beta} &= (X^T(\hat{\Sigma}^{-1} \otimes I_R)X)^{-1} X^T(\hat{\Sigma}^{-1} \otimes I_R)y \end{aligned} \quad (11)$$

The formula for the SUR estimator is as follows:

$$\sqrt{R}(\hat{\beta} - \beta) \xrightarrow{d} N(0, (\frac{1}{R} X^T (\hat{\Sigma}^{-1} \otimes I_R) X)^{-1}) \quad (12)$$

where:

R – the number of observations,

IR – the R-dimensional identity matrix,

$\otimes$ – denotes the matrix Kronecker product,

$\hat{\Sigma}$ – the matrix.

4. Results of the research

Figure 1 shows the number of manufacturing enterprises from 2008 to 2021. As the trend line shows, there was a quite sharp decline in the number of enterprises during the period under examination.

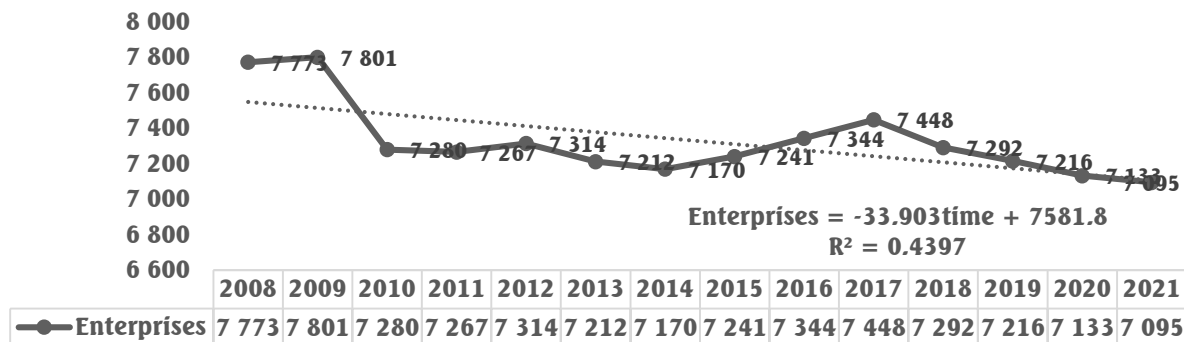


Figure 1. The number of manufacturing enterprises in Poland (2008-2021).

Source: own study on the basis of GUS [<https://stat.gov.pl/>], 17.07.2024.

The economic and social development of the sector has a positive trend, and the environmental trend is negative (Figure 2). In turn, environmental development has a negative trend (a particularly low indicator level occurred from 2016 to 2019 due to the great emphasis placed on financial results). The sustainable development index has a slight positive trend, which results from the level of economic and social development of the sector.

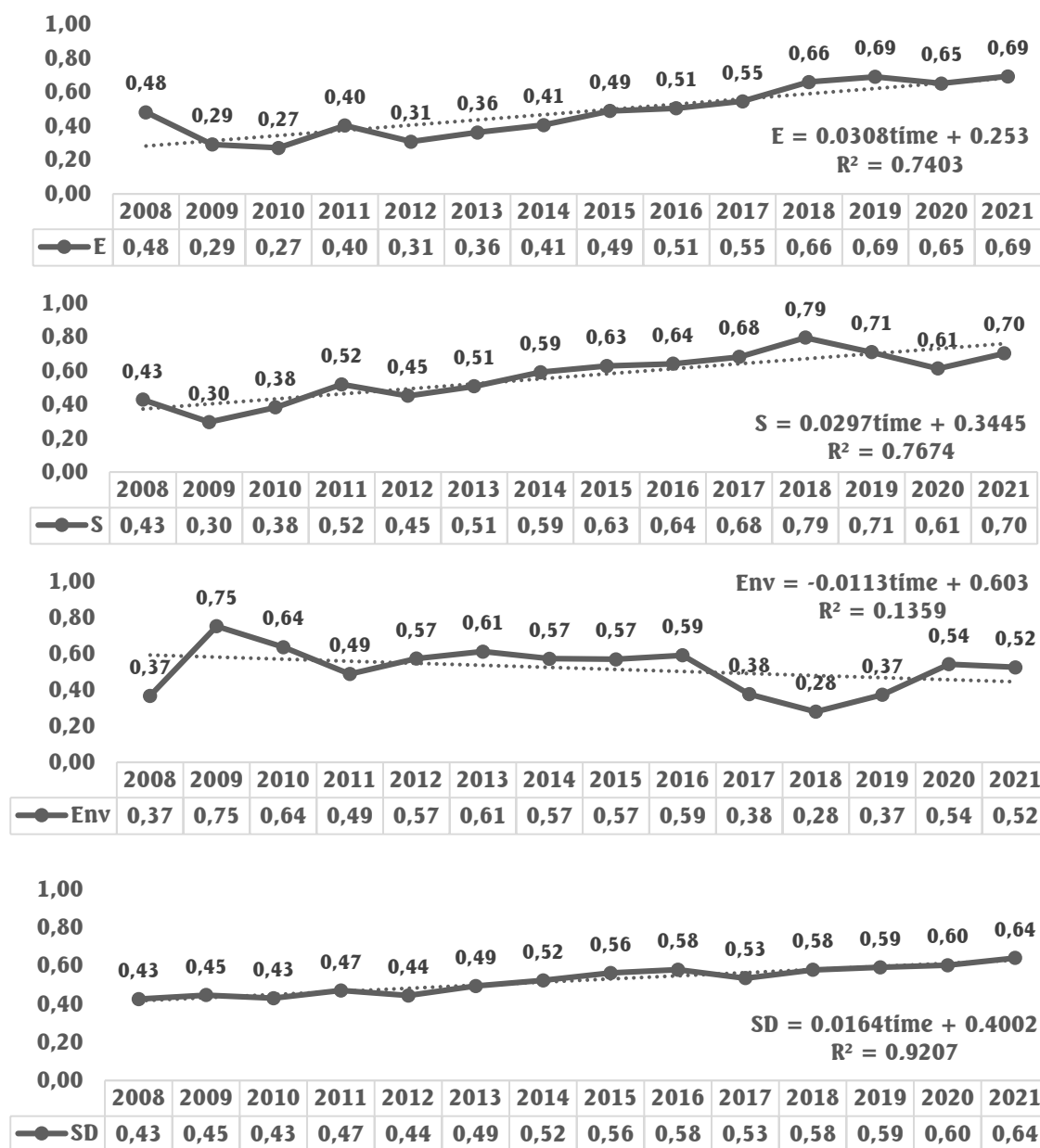


Figure 2. The indicator of sustainable development of manufacturing enterprises in Poland and its pillars (2008-2021).

Source: own study on the basis of Eurostat [<https://ec.europa.eu/Eurostat>], 17.07.2024.

Figure 3 shows the financial standing indicator, which has a positive trend in the years 2008 to 2017, then declines and increases during the Covid-19 pandemic, where the demand for products offered by the sector increased significantly.

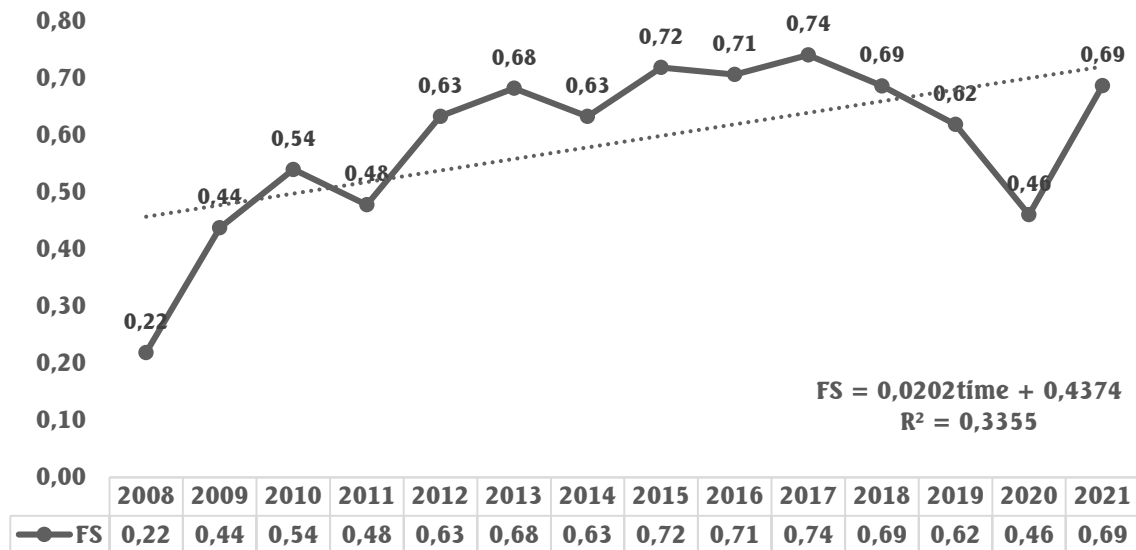


Figure 3. The indicator of financial standing of manufacturing enterprises in Poland (2008-2021).

Source: own study on the basis of Industry indicators [<https://wskaznikibranzowe.pl/>], 17.07.2024.

The linear correlation indicators between sustainable development and financial standing are at an average level, indicating a relatively low dependency level between the examined indicators. Moreover, it should be noted that this is a positive relationship, so an increase in one indicator leads to an increase in the other.

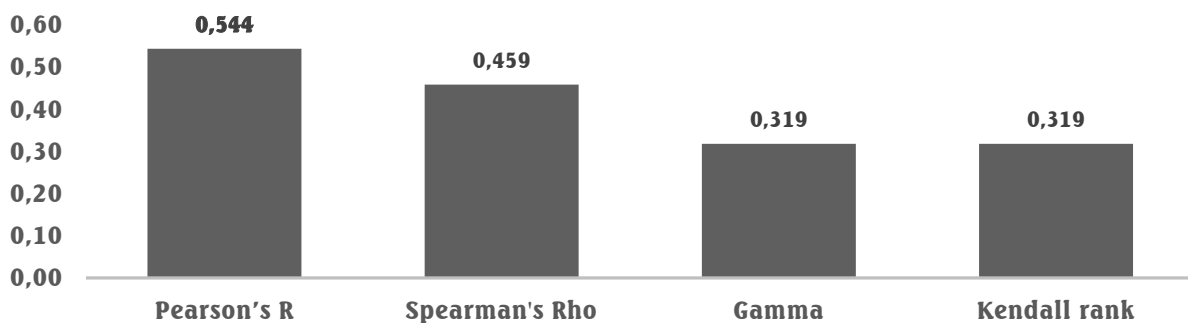


Figure 4. The Pearson's R, Spearman-s Rho, Gamma and Kendall rank correlation coefficients; correlation between SD and FS (2008-2021, $p < 0.05$).

Source: own study on the basis of Eurostat and Industry indicators [<https://ec.europa.eu/Eurostat>; <https://wskaznikibranzowe.pl/>], 17.07.2024.

The OLS estimation results indicate a strong impact of the financial standing on sustainable development from the previous period, which shows that financial decisions made earlier are important for development based on three economic, social and environmental pillars (Table 2).

Table 2.*The Results of the OLS regressions (2008-2021, $p < 0.05$)*

Country	Dependent variable	Independent variable	Coefficient	Std. error	P-value	R-squared
Poland	E	Const	0.044	0.123	0.729	0.594
		FS _(t-2)	0.772	0.202	0.003	
	S	Const	0.205	0.078	0.025	0.732
		FS _(t-2)	0.670	0.128	0.000	
	Env	Const	0.865	0.111	<0.0001	0.470
		FS _(t-1)	-0.577	0.185	0.010	
	SD	Const	0.338	0.054	<0.0001	0.589
		FS _(t-1)	0.338	0.089	0.004	

Source: own study on the basis of Eurostat and Industry indicators [<https://ec.europa.eu/Eurostat>; <https://wskaznikibranzowe.pl/>], 17.07.2024.

The results of the estimations show that good financial standing is important for the implementation of socially and ecologically responsible investments. It should be emphasized that managers and their owners still focus on economic and social development in industrial enterprises. It is necessary to take action to implement environmentally friendly technologies.

5. Discussion

Prior research on sustainable development and a company's financial situation has focused primarily on the relationship between the extent of sustainable development and single dimensions of a firm's economic performance, such as profitability (Nollet et al., 2016; Chouaibi et al., 2022), leverage (Zhao et al., 2018) and intellectual capital (Mikołajek-Gocejna, 2024; Giannopoulos et al., 2022). This paper contributes to the existing literature by evaluating the financial standing using the synthetic indicator and then assessing its impact on the magnitude of sustainable development of manufacturing enterprises in Poland.

In this study, we confirmed the central hypothesis that financial standing has a statistically significant and positive impact on the firm's sustainable development in the tested sample. In particular, we demonstrated that financial decisions from earlier periods (t-2 and t-1) are important for firm's development based on three ESG pillars in the current period (t). However, the directions of the effect of financial standing on the three pillars of sustainable development were diversified. Moreover, evaluating the relationships between the abovementioned variables could depend on the adopted calculation methods (OLS regression vs SUR regression).

We also found several interesting findings concerning the research questions. The distribution of the synthetic financial standing indicator for 2008-2021 indicates that the outbreak of the COVID-19 pandemic may have contributed to a sharp decline in its value in 2020 to an increase in 2021. It should be emphasized that the state of COVID-19 epidemic threat in Poland occurred in March 2020, and therefore, the entire year 2020 cannot be considered a pandemic year (Comporek, 2024). However, the research results confirm the

negative implications of economic downturns for manufacturing companies (Notta, Vlachvei, 2014; Khudyakova, Schmidt, 2019). Moreover, we gathered evidence that in the examined period, the greatest growth dynamics characterized the economic and social levels of sustainable development of the manufacturing sector in Poland. In turn, environmental development has a negative trend from 2008 to 2021, although paradoxically, the outbreak of the COVID-19 pandemic contributed positively to the formation of the environmental sustainable development indicator value.

This study must be viewed with consideration of several limitations. They are related to the selection of analytical variables for the synthetic indicators created, the range of the research period and the choice of model estimation methods. This research leads to several future studies in the area of determinants of sustainable development in the emerging market. Future analysis can identify the impact of financial standing on the extent of sustainable development in other sectors of the economy. Similarly, assessing the effect of the company's financial situation on its sustainable development in other CEE countries is worth further exploring.

6. Conclusions

The financial standing of manufacturing enterprises shows their competitive position in the market, credibility and economic strength and affects the level of trust of contractors and their loyalty. It is a measure that shows holistically the economic efficiency of an organization's functioning on the capital market and its ability to achieve its economic, social and individual goals.

The concept of shared value promoted by Porter and Kramer (2011) emphasizes that economic profit linked to the implementation of social and environmental goals is a higher form of capitalism. Thus, business success should go hand in hand with benefits created for society. The empirical studies show the impact of financial standing on the sustainable development of manufacturing enterprises in a positive light. We demonstrated that Polish companies with an established financial position can afford to implement socially and ecologically responsible investments to a greater extent than others. This observation mainly concerns two of the three pillars of sustainable development: economic and social.

Conclusions derived from the study could be of interest to the company's stakeholders, who pay attention to the choices made by managers regarding actions contributing to the protection and multiplication of social well-being. Practical implications resulting from the research focus on the presentation of diverse econometric tools that can be used to evaluate the impact of financial standing on sustainable development. Theoretical implications include a review of the existing literature. They also allow for further theoretical and empirical inferencing based on the analyses presented in the paper.

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WOMEN'S CAREER MANAGEMENT AFTER MATERNITY LEAVE

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Purpose: The aim of this article is to analyse the impact of motherhood on women's career management and to identify factors that enable them to pursue their chosen career path within an organisation.

Design/methodology/approach: This study used a qualitative approach. Face-to-face, semi-structured, in-depth interviews were conducted with women who had returned to work after maternity leave. This method was chosen due to the complexity and subjective nature of career management in the context of motherhood. The aim was not to make statistical generalisations, but to understand the experiences and decision-making processes of the women surveyed.

Findings: In the respondents' opinion, the birth of a child does not mean completely giving up career goals, but rather the need to logistically renegotiate one's career path, in which social and organisational support plays a key role.

Research limitations/implications: The main limitation of this study is the small size of the research group, which makes it impossible to generalise the conclusions to the entire population of women returning to work after maternity leave. The study is focusing on understanding individual experiences rather than providing a statistical description of the phenomenon.

Practical implications: The results of the study are a valuable source of knowledge that can be used to design and implement reboarding programmes for women returning to work after maternity leave and wishing to continue pursuing their career goals.

Social implications: The results show that motherhood requires a change in career management models, but does not diminish competence. A clearly defined career path after returning to work from maternity leave reduces stress levels, preventing burnout and feelings of exclusion.

Originality/value: The article provides a critical insight into the complex process of managing the career of a young mother, contributing to a better understanding and support of this key group of employees. The article is aimed at a wide audience – managers and HR staff responsible for personnel policy in organisations, researchers studying the impact of motherhood on career management, and young mothers who are looking for good practices for developing their careers during this special period of their lives.

Keywords: career management, career path, women's career patterns, maternity leave.

Category of the paper: Research paper.

1. Introduction

Women's professional careers often involve a synergy between the roles of mother and employee. Despite progress in gender equality, women still tend to take on more responsibilities related to childcare and housework, which makes it difficult to balance these with their careers and often leads to a conflict between professional ambitions and domestic duties. This imbalance can cause frustration and even burnout. Motherhood is often a turning point in a woman's career. It is a time when women may change their priorities and their career takes a back seat.

Returning to work after maternity leave is not always easy. This can be influenced by both personal factors, such as fear of leaving the child in the care of another person, and organisational factors, such as a lack of support from the employer in reintegrating into professional duties. Unfortunately, women may also experience discrimination during this period. Employers often perceive young mothers as less competent and committed to their work than non-mothers, and consequently discriminate against them in hiring and remuneration decisions (Correll, Benard, Paik, 2007). In the social sphere, women who pursue careers are often perceived as failing to fulfil their role as mothers. It should be emphasised that having children is not a necessity, but a matter of choice for every woman. More and more women are postponing this period or even consciously choosing not to have children in order to improve their quality of life or develop their careers.

In the literature on the subject, the topic of motherhood is often addressed and considered in various areas and aspects. Numerous studies have focused primarily on reconciling the roles of mother and employee, the well-being of working mothers, their situation in the labour market, and solutions supporting mothers on the part of partners, employers and the state (e.g. Hampson, 2018; Nippert-Eng, 1996; Greenhaus, Beutell, 1985; Anwar, Suhariadi, Fajrianthi, 2017; Garcia-Lorenzo et al., 2023). Research confirms that young mothers encounter many problems in pursuing their career paths and that only employers who are open to the evolution of best practices in maternity leave will attract and retain talented women (Brand, Barreiro-Lucas, 2014, p. 69). Research also suggests that professional experiences during pregnancy and return to work influence subsequent career decisions (Desjardins, Fortin, 2025, p. 3). Women are aware that during their absence due to childbirth, they may lose contact with their network, their job may change, and others may take over some of their responsibilities. As a result, they face increasing social uncertainty (their position in the group during and after pregnancy) and uncertainty about the future (what career opportunities and responsibilities will be available to them). For these reasons, during the important transition that childbirth represents, women are likely to be sensitive to signals of (in)justice (Desjardins, Fortin, 2025, p. 3). These episodes may be factors that, over time, trigger attitudes and behaviours associated with giving up one's career (Desjardins, Fortin, 2025, p. 19). Women who take a career break longer than two years find that their careers are stifled and limited (McIntosh et al., 2012).

Despite the popularity of the topic, the literature on the subject still does not sufficiently explore the specifics of career management for women returning to work after maternity leave. This area requires further systematic analysis, as existing approaches overlook certain aspects. The literature on human resource management is dominated by an institutional perspective, which creates space for analysing the individual perspective, which has been less frequently addressed so far. Firstly, most studies focus on systemic and organisational solutions and devote little space to information on how women after maternity leave shape their own career paths, what strategies they adopt and how they cope within the organisation to combine professional development with motherhood. Therefore, there is a justified need to deepen scientific reflection on women's individual strategies. Secondly, they often treat returning to work as a one-off event, whereas it is a process that begins much earlier. It is a time when women redefine themselves and their goals, which happens during their leave and continues after they return to work. Additionally, in organisational terms, studies focusing on informal barriers, such as managers' prejudices against young mothers, are difficult to capture in quantitative analyses, which usually reduce the penalty for motherhood to measurable indicators such as wage inequality or lack of promotion. It is also rarely pointed out that a negative attitude on the part of the employer can be an unplanned shock for young mothers, which affects their loyalty to the employer. The article analyses the subjective mechanisms of career management by women at a specific moment of transition, which is the return to work after maternity leave. It focuses on women's individual experiences, shows that returning to work is a process, and emphasises the importance of mental support and the manager's attitude in career management.

In order to answer the research question: Do women continue their careers in their chosen field after returning to work from maternity leave, ten individual in-depth interviews were conducted. The sample was purposively selected and included respondents of different ages, seniority and positions. The article analyses whether returning to work is associated with continuing the current career trajectory or whether it becomes an impulse for professional reorientation. In addition, the determinants of these changes were explored, with particular emphasis on the role of the work environment. This article is a valuable source of knowledge both for women consciously planning their motherhood and managing their own careers, as well as for employers responsible for developing company policies focused on creating a workplace that is friendly to young mothers, where they can pursue their career goals. It enriches the literature on the subject by offering an in-depth insight into the experiences of women returning to work after maternity leave. It helps to understand how mothers actively shape their position in the organisation and adapt their career plans to their new life situation. It also points to the key role of managerial attitudes. It suggests that the role of the employer does not end with providing statutory benefits, but consists in actively supporting mothers in their career development. The conclusions of the article also have significant practical value for HR departments and management. They allow for a better understanding of the psychological

and logistical needs of employees, which can translate into building more effective and inclusive organisational cultures.

2. Literature review

Career management can be defined as the process of planning and implementing activities related to an employee's professional development. It is the ideal match between the organisation and the individual (King, 2004). It is a process in which people develop, implement and monitor career goals and strategies (Greenhaus, Callanan, Godshalk, 2000, p. 12). Employees manage their careers taking into account their individual interests and motivation as well as their biological and social development. From the organisation's point of view, career management means supporting the professional development of employees by offering them appropriate solutions (Jarosik-Michalak, 2018, p. 128). This process requires constant communication between the employee and their superiors and the HR department in order to be able to adapt career plans to changing market conditions and the employee's personal aspirations. It should enable employees to plan their own career paths, taking into account their needs and development opportunities (Jarosik-Michalak, 2018, p. 126).

Women's careers differ significantly from men's careers. Men tend to follow more linear career paths, while women's careers are more non-linear, chaotic and interrupted (Mainiero, Sullivan, 2006). During their professional lives, women's focus often shifts as they try to balance work and family life. This shift in focus may explain why women choose flexibility strategies, including reduced working hours and career breaks, which typically hinder their career advancement (Desjardins, Fortin, 2025, p. 3). Career patterns typical for women were identified by D.E. Super (1957). They differ from men's career patterns due to cultural conditions. Within this division, it was established that women can play the role of a housewife who is fully focused on the family. Another career pattern is a conventional career involving taking up work after completing education and developing it until starting a family, and an interrupted career involving interrupting or limiting satisfying work. Super also pointed to stable and unstable career patterns. The first is based on the assumption that work is a role to be fulfilled. The second type involves interrupting one's career depending on professional and personal circumstances. Women may also pursue a career of multiple attempts, which, like an unstable career, involves changes, in this case caused by inadequately met needs. Super also distinguished a dual-track career characterised by finding a balance between professional activity and fulfilling domestic responsibilities. This career pattern is most commonly pursued nowadays due to the high aspirations of women who no longer want to just take care of the home, but also achieve high results and social status. Within this division, we note that the roles women can play are not solely dependent on gender, but also on the motivations and needs of women themselves.

Duda (2019) describes how women adopt different career development strategies, which is related to the difficulties they encounter in their professional and family lives. The first group consists of women who focus primarily on their professional life, postponing motherhood on the assumption that their position will make it easier for them to return to work and pursue their chosen path. The second group includes women who decide to have children before entering the labour market, as they assume that early motherhood and raising children can be an asset when looking for a job. Another group of women combines motherhood with professional work, and this state of affairs motivates them to act. The fourth group consists of women who give up work during motherhood and, although they declare that they may return to work one day, in reality they do not plan to do so. The last group consists of women who did not plan to have children and have no professional experience, and having a child has, at least for a while, freed them from having to think about their future.

Women who decide to become mothers often have to give up their careers, as returning to the same job is either impossible or very difficult to adjust to the new reality. Maternity leave and motherhood are usually associated with serious consequences for women's careers. Some studies suggest that this may be due to women resigning (the so-called pull dynamic), while other studies show that mothers may be pushed out by organisations (the so-called push dynamic) (Desjardins, Fortin, 2025, p. 1). Taking up professional work and fulfilling a professional role requires women to commit to their own professional careers, but many women are unable to effectively combine different roles with the pursuit of self-fulfilment in their professional work (Christoph, Krause, 2019, p. 199). It should be emphasised that keeping their skills up to date is an important challenge for women who stop working, as knowledge and skills are one of the key elements of a smart career (Cabrera, 2007).

Rapid changes in the organisation's environment, the development of new technologies and artificial intelligence, as well as uncertainty related to the geopolitical situation, mean that career management requires employees to take on new roles and activities that increase their value in the labour market. This is particularly difficult for women who decide to become mothers, as this entails additional difficulties in fulfilling their professional duties. Work strengthens a woman's professional position in the family, because through work she not only contributes to the household budget, but also becomes financially independent, which has an impact on her self-confidence and self-esteem (Kwak, Pascall, 2005) and provides the foundation for future pension security (Baszczak et al., 2022).

Women's professional work is also associated with many limitations and negative consequences. The most frequently reported include a lack of time for family, friends and acquaintances, and for fulfilling household duties (Szyszka, 2015, p. 139). Interestingly, it also happens that women themselves give up promotions because the new position would require greater availability and involve responsibilities that may require overtime work (Kielczewska, Kukołowicz, Wincewicz, 2022). Women are also more likely to be overlooked for promotions and generally earn less than men. Gender discrimination against women in the labour market

reduces the availability of talent in the economy, which has negative economic consequences (Esteve-Volart, 2004). Women's work is extremely important for a country's economy. Countries with efficient health, education and social care systems, where women make up the majority of the workforce, were able to absorb the costs of the pandemic more quickly and restart their economies earlier. Equality is a key element of development based on an economy of care and respect for the natural environment (RSKK, 2023). It can also have a negative impact on society by increasing mistrust. The level of female employment in Poland is moderate compared to other European Union countries (Polski Instytut Ekonomiczny, 2023). Women's economic activity is linked to childcare, and among mothers of children aged 1-3, the economic activity rate is 62% – 26% lower than among women without children. This rate increases with the age of the youngest child, which is due to the fact that some mothers resume their professional activity as their children grow up.

The main reasons for returning to work after maternity leave are mainly fear of losing one's job and position, as well as the obsolescence of one's knowledge and difficulty in reintegrating into work (Rękas, 2013, p. 129). A CBOS survey (2022) shows that other motivating factors include a salary that would cover the costs of raising a child or children (30%), facilities to facilitate professional work, flexible working hours, the possibility of part-time and remote work (28%), and easy access to nurseries and kindergartens (27%). A step in the right direction is the implementation of the Work-Life Balance Directive in March 2023, which allows parents to make greater use of flexible working hours and, thanks to the introduction of additional leave for fathers, may reduce the asymmetry in the division of care responsibilities (RSKK, 2023). When choosing between full commitment to motherhood and pursuing a professional career, women often postpone or completely reject procreative decisions due to their desire for self-fulfilment and professional success (Krause, 2018, pp. 73-74).

The *State of Motherhood in Europe 2024* report conducted by the international non-governmental organisation Make Mothers Matter (MMM) shows that motherhood has a negative impact on mothers' professional careers, with 20% believing that it disrupts their career development. The most frequently cited negative effects of motherhood in Poland are job loss (37%), reduced working hours (16%) and a change in professional status after childbirth (52%). Only 36% of mothers saw benefits from a gradual return to work, 48% from changes in working hours, and only 31% gained access to teleworking opportunities (MMM, 2025).

Another report, *Motherhood and Professional Activity* (2021), prepared by the “Parent in the City” Foundation as part of the “I Work and Raise Children” project, it can be seen that almost 50% of mothers of children under the age of 3 do not return to work due to a lack of access to childcare, and they cite the inability to combine work and parental responsibilities as the main reason. Young mothers want to work, with as many as 94.4% declaring their willingness to return to the labour market, 52.7% of them immediately after maternity leave, but employers often view women through the prism of their motherhood rather than their skills.

Women consider flexibility in terms of place and hours of work to be the most supportive solution, with as many as 48% valuing the possibility of remote work. One in three mothers considered the atmosphere at work to be a factor facilitating their return to work. Interestingly, 24% of mothers fear a lack of understanding on the part of their employer regarding their role as a mother.

Research on returning to work after maternity leave shows that women, despite their positive perception of work, find returning to work difficult. There is also a significant change in the participants' attitude towards their professional career after childbirth. This change is not necessarily negative and should not be interpreted as a sign of a loss of interest in their professional careers. However, it highlights the need for appropriate management of the entire process – from pregnancy in the workplace to the return of employees to work (Brandt, Barreiro-Lucas, 2019). Other studies reveal a clear tendency to continue academic and professional qualifications and to pursue a second career after returning to work (Geber, 2000). Research by Roch et al. (2023) reveal that women face socio-cultural challenges, including work-life balance issues, poor jokes and moral harassment. The prejudice they experience makes them feel insecure and low in confidence in their work. In addition, they typically lack a support network during and after maternity leave, which results in feelings of overload.

3. Methods

The aim of the research was to determine whether motherhood has an impact on career management and to identify barriers to development and solutions that will enable young mothers to continue the career path they chose before giving birth or to embark on a new one, while at the same time allowing employers to harness their potential and thus retain the right employees to achieve the organisation's goals.

The specific objectives were as follows:

1. The perception of the concept of professional career by the women surveyed.
2. Identification of the career paths preferred by young mothers before giving birth.
3. Identification of activities undertaken by young mothers during maternity leave in order to manage their own professional careers.
4. Identification of factors determining a change in the chosen career path.
5. Determination of the type of support provided by the employer in the implementation of duties.
6. Identifying barriers to professional development.
7. Identifying organisational solutions for young mothers that facilitate conscious planning and shaping of their career paths.

The research process was organised in such a way as to obtain reliable data on career management by young mothers. In the first stage, the research sample was defined and the method of obtaining information was established. The sample selection was purposeful. The research population consisted of women who, after maternity leave, took up employment or resigned from professional activity after the birth of a child. These women had different levels of education, marital status, seniority, and job positions. They were employees of organisations representing various industries and employing different numbers of people. Due to the personal nature of the study, selected young mothers were asked to express their willingness to participate in the study in person. The author of the study wanted to obtain reliable and honest answers, so the focus was primarily on obtaining in-depth answers within the analysed areas, rather than on collecting general data.

The study was preceded by an analysis of the literature on the subject, which made it possible to present the most important issues, the results of published studies and reports addressing the issue of women's career management. This knowledge contributed to the formulation of methodological assumptions and the preparation of a set of questions addressed to selected women. Data was collected using semi-structured, in-depth interviews. The questions were designed to obtain the necessary information about the situation of women in terms of their career development before and after returning to work after maternity leave. The focus was on three areas. The first concerned the challenges at the intersection of professional and parental life that young mothers face in the first years after the birth of a child and their impact on professional decisions and career trajectories. The second area focused on the career management strategies that young mothers use to achieve their professional goals and achieve work-life balance. It was also important to determine how young mothers redefine their career goals and professional ambitions in the context of their new role in life. The third area examined external factors that can positively influence career management. Attention was paid to both sources of social support (husband/partner, family, friends) and organisational policy and the involvement of managers, HR departments and colleagues in helping young mothers settle into their professional duties.

The study was conducted using individual in-depth interviews conducted by telephone. The average duration of each session was 50 minutes. The research process was carried out in accordance with ethical principles. Participants were informed about the objectives of the study, assured of anonymity, and given the option to withdraw from participation at any stage. Due to the respondents' refusal to consent to audio recording, the documentation was prepared in the form of real-time notes, which were then anonymised by assigning appropriate names (pseudonyms) to the files in order to protect the participants' identities. The collected material was subjected to qualitative analysis. In order to increase reliability, consistency was ensured between the research questions, the interview script and the areas of analysis. The article also includes quotes from the participants' statements to enable an assessment of the extent to which the conclusions are rooted in the data.

Although there are certain limitations to the methodology used, the results provide valuable data for both young mothers and employers on how to consciously manage their professional careers. Although the study provided rich qualitative data, its limitation is the size and specificity of the sample, which limits generalisation. It is also worth noting that the results are based on the subjective feelings of the respondents, which may be subject to interpretative error resulting from their personal experiences and the specific nature of the industries in which they are employed. Further research should focus on comparing the strategies of young mothers and quantitative analysis to validate the findings in a larger population. An interesting direction for further analysis would be to compare the opinions of women with the perspective of management or HR departments to examine whether the perceived limitations to development stem from systemic barriers within the organisation or from women's self-perception of their own role. It is also worth examining the extent to which new forms of work and other facilities for young mothers actually eliminate barriers to career management.

4. Results

The study covered 10 women aged between 23 and 39. The average age of the respondents was 33. The dominant age group was 30-39, which included the majority of respondents. Half of the respondents had higher education, which may indicate their high professional ambitions and potential for career development. Four women have secondary education and one has primary education. The vast majority of women (70%) are married. The largest group (60%) are women raising two children, one mother has three children, and for the rest it is their first time being parents. The respondents have varying lengths of service (from 4 to 18 years), with an average of around 11 years, which indicates that most of them are people with established professional experience. Half of the respondents work in small organisations, which may affect flexibility and work culture after returning from maternity leave. Two women work in organisations with 50 to 249 employees, and three are employees of large organisations. The respondents represent a wide range of industries (8 different ones), which may indicate the universality of the challenges associated with career management after maternity leave, regardless of the sector. Among those mentioned were: education, manufacturing, beauty, medicine, banking, catering, energy and finance.

An analysis of the collected research material allows us to conclude that the respondents show a similar interpretation of the concept of professional career. Their perception is dominated by a developmental paradigm – a career is identified primarily with the progressive improvement of competences, promotion within the hierarchical structures of an organisation, and the successive achievement of professional goals. For some of the respondents, an important aspect of a career is self-verification of their own value and the pursuit of improved

financial status. In one case, the emancipatory function of work was noted, understood as a space for leaving the domestic sphere.

All respondents declared that they were actively pursuing their career paths before becoming mothers. In addition to routinely fulfilling their professional duties, a significant part of the group (6 women) undertook systematic activities in the area of their careers, participating in internal training and external courses that were highly relevant to their professional profiles. Two respondents showed particular proactivity by undertaking higher education and postgraduate studies in order to prepare themselves for specialist roles. With regard to preferred career types, the majority of respondents (6 people) leaned towards a model focused on structural promotion and financial rewards. Two respondents preferred an expert path (specialisation), while two women preferred an autonomous, entrepreneurship-based career model. The vast majority of respondents (7 women) remained professionally active during pregnancy (from the fifth to the ninth month). During this period, they performed their duties as usual. Some women, due to feeling unwell, had their supervisor's permission to finish work a little earlier or to perform some of their tasks remotely from home. One of the women surveyed worked fewer hours than before during her pregnancy and performed lighter work. One woman did not work due to her health and personal circumstances, and two deliberately took sick leave at the beginning of their pregnancies because their superiors were unwilling to extend their contracts after the birth of their children. These were people who were employed on a fixed-term basis.

In terms of childcare and upbringing, almost all respondents received support in raising their children. Most often, it was their husbands/partners who helped, slightly less often their parents and siblings, and occasionally friends or a nanny. It is worth noting an important voice in the discussion on the division of roles, in which one of the respondents considered childcare not as "help" but as a shared and equal role of both parents:

My partner was also involved in raising the child, but I would not call it help, because taking care of the child is our shared responsibility.

The maternity leave period was characterised by a dichotomy of attitudes. Half of the respondents maintained contact with the labour market through online training, postgraduate studies or monitoring industry trends. One person was looking for a new job during this period and searching for offers that matched their qualifications. The remaining group completely suspended their professional activity in favour of family life, motivating this with a desire to fully celebrate motherhood or the burden of household duties.

All respondents took full advantage of their maternity leave entitlement. In 9 out of 10 cases, the decision to return to work was motivated by financial considerations. Half of the women also indicated a desire for professional development and fears of losing their skills or even their jobs. The decision to return was mostly made jointly with the husband or partner. The process of returning to work varied: four women returned to their previous positions, while the others experienced internal or external rotation. The change of employer was often motivated by fear

of excessive workload (work-family conflict) and the search for an organisational culture that was more inclusive towards parents. The positives of these decisions included: a position more suited to their competences, greater opportunities for development, and the company's location closer to their place of residence. Although most experiences related to returning to work were positive (flexibility, mentoring, onboarding), there were cases of regression in employment conditions and a lack of support from management. Support from colleagues proved to be a key resource in the adaptation process.

The return to work was accompanied by emotional ambivalence. On the one hand, there was satisfaction at regaining professional activity and social interaction, and on the other, a strong fear of sanctions for a child's sick leave. As one mother put it:

I was afraid of my children getting sick and having to take sick leave. I was afraid that motherhood would interfere with my professional duties and that my employer would take a dim view of my frequent absences.

There was also stress related to getting used to new responsibilities and learning new programmes or technologies. There were also these responses:

I was sad that I was offered worse working conditions.

When I returned to work after maternity leave, I received no support from my employer in returning to my duties. I was offered worse working conditions and, consequently, fewer financial opportunities. Only my colleagues at work gave me a helping hand.

Returning to work was a shock for me because I didn't know if I could handle it. A lot had changed in my industry over the course of a year. I was afraid to ask for help, lest it be perceived as a lack of competence.

Unfortunately, when I returned to work, my employer did not take any steps to assist me. I had to organise my work myself.

According to most respondents, becoming a mother did not change how they were perceived by their employer, and two of the mothers were even offered training opportunities. One mother did not notice any advantages or limitations in access to training or promotion. For one mother, becoming a mother meant fewer financial and development opportunities. Two of the mothers also had their contracts terminated and felt resentment from their employers. One of the mothers summed it up by saying:

I felt that being a mother was inconvenient for my employer. I felt that my supervisor was not positively disposed towards me.

The impact of motherhood on career development is assessed ambiguously. Although most women continued to pursue their previously chosen goals, many of them indicated a slowdown in the pace of promotion. In the perception of the respondents, motherhood did not change their ambitions, but forced them to redefine their time and energy management strategies, with social support proving to be a key moderator of success in this area. The new situation was associated with difficulties on their chosen career path, but did not mean giving up on their goals.

Motherhood delayed my professional development, but my professional goals have not changed.

One of the mothers pointed out that motherhood did not affect her career development, but without the support of her loved ones, it would have been impossible. Some women became even more committed to achieving the goals they had set before giving birth. There were also women who said that it did not hinder their development, but their priorities had changed.

According to the respondents, motherhood can limit career development and affect a woman's value in the labour market. This is mainly due to a lack of time for professional activity and self-development:

It is difficult to reconcile caring for a small child with working or continuing education. It is possible, but it requires determination and little sleep.

Only two mothers felt that motherhood motivates development:

Having children motivates development because we want to be able to provide our children with a good quality of life.

All respondents agreed that support from their families, especially their husbands/partners, made it easier to pursue their chosen career paths. According to the women surveyed, time management skills are also important. One of the mothers also pointed out the role of the state in supporting young mothers as an important factor in helping them achieve their professional goals. Among the answers to the question of what measures employers should take to effectively manage the careers of their employees after maternity leave, the most frequently mentioned were: treat them equally with other employees, create opportunities for development, be positive towards young mothers, create opportunities to combine work and private life, e.g. through flexible working hours, remote/hybrid work, reboarding programmes to keep young mothers up to date with changes at work, support with kind words and provide psychological support if necessary.

5. Discussion

This study, based on an in-depth analysis of responses from young mothers, shows that a major challenge in career management is the difficulty of fulfilling both caregiving and professional responsibilities simultaneously. These observations are strongly supported by Greenhaus and Beutell's (1985) work-family conflict theory. This model specifies the mechanisms of conflict formation, identifying three sources of conflict. Conflict between work and family occurs when: the time devoted to the demands of one role makes it difficult to meet the demands of another role; the burden of participating in one role makes it difficult to meet the demands of another role; and certain behaviours required by one role make it difficult to meet the demands of another role (Greenhaus, Beutell, 1985, p. 76). In this view, the slowdown

in professional career advancement shown by the research can be considered a direct result of the difficulty in reconciling both roles. It is worth noting, however, that the women surveyed do not see the causes of these difficulties solely in the lack of their own time, but also in insufficient support from the system and their employers.

The analysis is deepened by Clark's (2000) boundary theory, which allows us to view the mothers studied not as victims of conflict, but as active agents managing boundaries. The author analyses how negotiating physical, temporal and psychological boundaries between spheres affects the achievement of balance (Clark, 2000). This study emphasises that it is the ability to effectively manage these transitions that determines the continuity of women's professional development after childbirth. In this context, the slowdown in career development is not merely a passive effect of overload, but a conscious mechanism for regulating the physical and psychological boundaries between these spheres. This corresponds to the concept of Nippert-Eng (1996), which assumes that individuals create separate spheres of home and work by building physical and psychological barriers. The degree of this separation falls within the integration-segmentation continuum. In light of the results obtained, a temporary slowdown in one's career can be interpreted as a rational strategy for increasing segmentation. It serves to protect family identity from the dominance of the professional sphere. At the same time, the subjective sense of balance is conditioned not only by personal competences, but also by negotiations with employers, partners and other family members. This means that the process of reconciling roles is a relational and structural challenge, not just an individual one.

The results of the study shed interesting light on the dynamics of women returning to work after a maternity leave. Particularly striking is the discrepancy between the declared support of organisations and the actual experiences of women, who still face the phenomenon of maternity penalty. This confirms the diagnosis made by Correll, Benard and Paik (2007) that motherhood is still often seen by employers as a sign of lower commitment, which is a barrier that is difficult to overcome even with high qualifications. In this context, it is crucial to view the deterioration of material conditions and non-renewal of employment not only as an economic problem, but above all as a career shock. In the literature, career shock has been defined by Akkermans, Seibert and Mol (2018, p. 4) as "a destructive and extraordinary event that is, at least to some extent, caused by factors beyond the individual's control and that triggers a conscious thought process about their career". This approach helps to understand why returning to work is a moment of crisis for many women. If, instead of support, the organisation offers the employee a negative impulse, this triggers a rapid process of reevaluating their career to date. Such a shock can destroy the social capital of an organisation, damaging trust that cannot be easily rebuilt. Instead of a loyal and experienced employee, the organisation gains an emotionally distant person who feels compelled to seek a new career path outside the structures of their current employer.

An interesting phenomenon is the grassroots attempt to counteract these negative effects through educational activities undertaken by mothers while still on maternity leave. The actions taken during this period can be interpreted as an attempt to deliberately build career capital in order to minimise the effects of the anticipated career shock. This demonstrates the high level of agency of women, but at the same time exposes the weakness of the organisational culture of the companies surveyed. If mothers feel pressure to maintain constant professional readiness, it means that work-life balance in many workplaces remains nothing more than an empty slogan. The challenge for HR practitioners is therefore to create implementation systems that are not just a formality, but actually help to manage the competence gap and neutralise managers' unconscious biases. Although this study is based on the subjective feelings of the respondents, it is precisely this subjective perspective that allows us to understand the emotional cost of career management. Without taking this human dimension into account, the struggle to retain talent in organisations seems doomed to failure.

6. Conclusions

Young mothers treat their careers as a means of developing their skills, advancing within the company structure and achieving professional goals. Their return to work begins while they are still on maternity leave. Some women invest in education and new skills so as not to fall out of the market and prepare for specialist roles, while others deliberately give up their professional activity. This shows that young mothers are aware that it is worth setting realistic professional goals during this period. It is also worth taking advantage of opportunities that will allow them to develop their skills and build networks. Although the main motivation for returning to work is financial and the desire to avoid routine, the process is very stressful. Women fear losing their jobs, technological changes in their organisation and a lack of understanding from their superiors in the event of their child falling ill. The study shows that another problem is the deterioration of working conditions after returning to work or the non-renewal of fixed-term contracts. Such actions by employers are harmful because they weaken employees' identification with the company's mission, which in the long run reduces the efficiency of the entire organisation and forces mothers to look for work with more friendly competitors. Interestingly, mothers can usually count on the support of their colleagues, but they often lack support from their managers.

To retain skilled female employees, employers should consider implementing formal reboarding programmes focused on filling skills gaps, gradually increasing workloads and, depending on needs, coaching or mentoring sessions as career management practices. Training for managers is also key to ensure that they do not discriminate against mothers exercising their rights. Success in combining professional and domestic responsibilities depends on a woman's

determination, but it also requires support from her family, the state and a modern approach from HR departments, which can offer returning mothers dedicated digital skills update programmes to minimise the shock of returning after a long absence.

The publication enriches the literature on the subject with an analysis of the experiences of women returning to work, highlighting their active influence on shaping their career paths and the key importance of support from their superiors. The results of the study also have practical applications for HR departments, as they help to create friendly workplaces that better respond to the real needs of young mothers.

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THE ROLE OF SEMANTIC NETWORK IN MANAGEMENT

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Purpose: The aim of this article is to present useful issues related to the role of semantic network structures used in management forms based on systemically structured data sets.

Design/methodology/approach: The methodology used is carried out by successively characterising the areas of issues included in semantic network structures.

Findings: Components, search engines, tools and platforms illustrate the results of analysing original procedures that allow a selected group of managers to take advantage of the originality of their structures.

Originality/value: The description of semantic network structures can provide management leaders with practical solutions for using professional implications, drawing on their exceptional intuition.

Keywords: Semantic network, ontology, software agents.

Category of the paper: Conceptual paper.

1. Introduction

The Semantic Web was not created from scratch, but was developed from the existing *World Wide Web* – thanks to the precise definition of the meaning of the data available on it, which allowed for closer cooperation between humans and computers. The vision of such a web was presented in the late 1990s by the creator of the *World Wide Web*, Tim Berners-Lee (Nahotko, 2003).

The main problems that the Semantic Web was supposed to solve were:

- Computers recognise the structure of hypertext pages and their typical elements – headings, links to other pages – but they cannot read the meaning of the elements they contain.
- Internet search engines do not take context into account, which means they cannot properly interpret and distinguish between homonyms and synonyms.

- In response to a search query, modern search engines return a list of web page addresses primarily based on the number of occurrences of so-called "keywords" – treated as character patterns.

The Semantic Web has become the solution to the above problems. It will allow the systematic assignment of meaning to elements of *web* pages, thanks to which the programmes that read them, called software agents, will be able to perform complex tasks assigned to them by users.

In order to implement the idea *of the Semantic Web* to exchange information and knowledge between different applications, a common terminology is needed to describe the domain in which these applications operate. Information about the relationships between them is also needed. Such a set of terms and relationships is called ontology (Węcel, 2003).

2. Components of the Semantic Web

- XML is a universal markup language designed to represent various data in a structured manner. It allows users to define and use their own tags. It does not have built-in mechanisms that enable other users to understand new tags.
- XML Schema is a language that introduces restrictions on the type and structure of data in XML documents to ensure that XML data is syntactically correct.
- RDF is a standard that allows data to be stored in the form of a directed graph. In this graph, the data is contained in the vertices, and the relationships between them and their properties are contained in the edges.
- RDF Schema introduces concepts such as classes and subclasses to graphs, allowing data with common characteristics to be grouped together. Any given piece of data can belong to multiple classes.
- OWL is a standard that allows classes to be defined based on data properties, as well as logical characteristics of relationships. OWL is therefore a standard that formally records ontologies.
- Ontologies are sets of statements recorded, for example, in RDF, defining relationships between concepts and setting rules for inference. Computers will be able to understand the semantic content of web documents by making references to the ontologies to which the concepts occurring in them refer.

Ontologies provide the terminology for such a description. It can be taken from classified domains, not necessarily dependent ones. In addition, ontologies must define logical relationships between concepts in order to ensure a deep level of analysis, as well as methods of search and intelligent inference by computer programs (Gładysz, 2017).

This leads to a comparison of a semantic network to an ontology-based knowledge management system, in which ontologies provide tools for the formal description of knowledge. Based on such a description, computer programmes can search and process data. It is thanks to ontologies that it is possible to integrate the vast amount of heterogeneous documents currently existing on the Internet.

The concept of ontology can also be viewed in the context of a model of a fragment of reality representing interesting objects and the relationships between them, as well as containing the required properties (attributes) of these objects (Perkowski, 2003).

The idea of *the Semantic Web* and the creation of *Semantic Web Services (SWS)* can be presented in three stages (Krukowski, 2005):

- Stage 1. Formulating the goal

A user in *the Semantic Web* is represented by their software agent (e.g. a semantic search engine application), which contains, among other things, information on authorisation and security. The tasks carried out in the first stage are as follows:

- the user enters their request (in natural language),
- the semantic browser (using a language analyser) records this request using one or more ontologies; the request constructed in this way is called a goal; standardised ontologies are stored in a publicly accessible repository.

- Stage 2. SWS search

Having formulated the objective, the user's programme agent connects to the intermediate layer agent and transmits the specific objective to it. Each request sent is assigned to an intermediate layer agent with access to the ontology repository, the goal repository, and the service description repository. The task of the intermediate layer agent is to search for services whose semantic description would be most compatible with the goal expressed by the user.

- Stage 3. Invoking web services

Once the middle layer agent has constructed an execution chain from individual services, based on their semantic description, the individual services are invoked. They are represented by their agents. During the execution of the task flow chain, the middle layer agent continuously monitors its execution, communicating with individual service agents. Its responsibilities also include presenting the final results to the user.

The functioning of the Semantic Web in a simplified form has been presented in Figure 1.

Extensive research is being conducted on semantic search engines, which allow queries to be asked in natural language, and the returned results provide justifications of their application. Search engines should be equipped with additional links to pages containing more information.

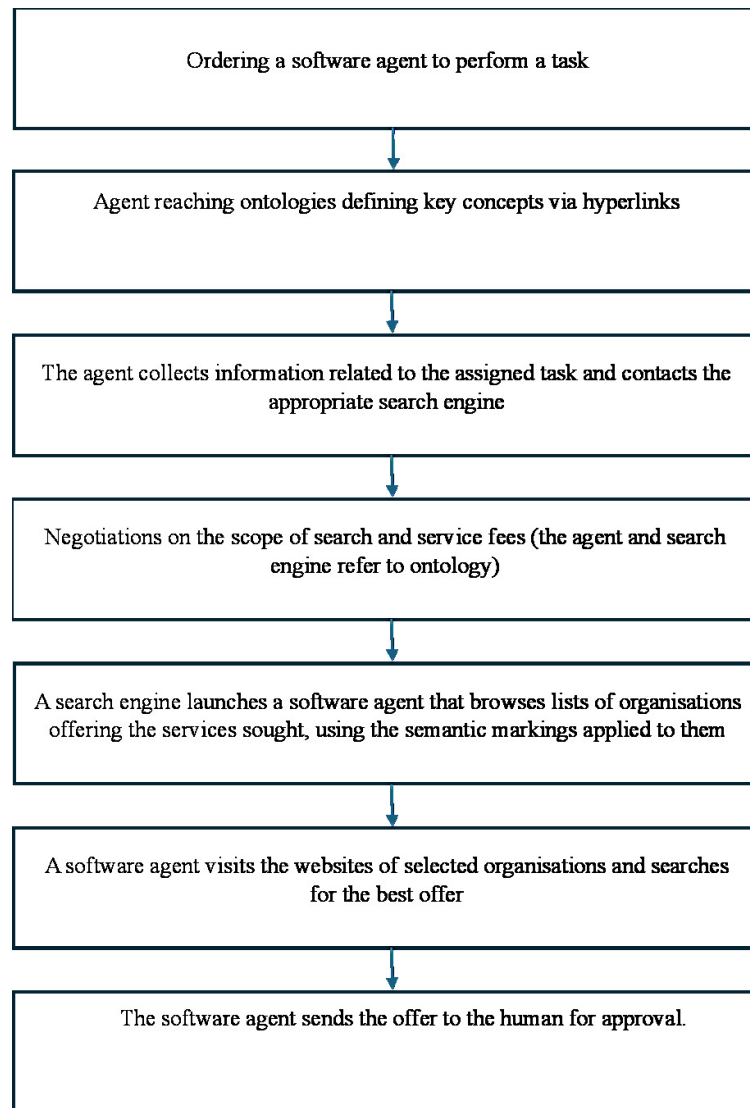


Figure 1. General structure of the Semantic Web.

Source: own work (Kiełtyka, 2020).

3. Semantic search engines

- Cuil search engine – this application features modern technology for indexing web resources and handling user queries. It provides very accurate search results. Cuil does not catalogue pages based solely on keywords taken out of key words taken from the content, but based on the connections between terms, creating natural chains of associations between them. This is a semantic approach; it does not use artificial intelligence to guess the meanings of indexed sentences. It uses a more effective algorithm that simply categorises websites more precisely (Maj, 2008).

- PowerSet (<http://www.powerset.com/>) – is a powerful semantic search engine owned by Microsoft. The tool allows you to define queries in natural language (English only). Answers are provided based on data from websites and the Freebase database (<http://www.freebase.com/>). By "understanding" the content of the query, the search engine allows you to obtain the most relevant results.
- Yahoo! SearchMonkey – displays additional links attached to the results already obtained. In addition, it is possible to create your own applications based on SearchMonkey search mechanisms.
- Rich Snippets – a tool from Google.
- Hakia (<http://hakia.com/>) – initially, the search engine was developed with the share of the Polish company PROKOM INVEST-MENTS S.A.

Thanks to this, the Polish language is offered. The tool is in the beta phase. Responses to queries may include specific facts, related links and photos.

An indispensable element of *the Semantic Web* is the digital signature – encrypted data blocks used by computers to verify that the downloaded information actually comes from a specific, trustworthy source. Agents should be sceptical about information found on *the Semantic Web* and verify its sources each time.

The true potential of *the Semantic Web* will be revealed when many programmes are developed that are capable of collecting information from various Internet sources, processing it, and exchanging the results with each other. Communication between humans and computers will then take on a new character, bringing it closer to the level of communication between humans (Kiełtyka, 2013).

Currently, attention should be paid to the rapidly developing area of management tools and platforms, especially when using Semantic Networks.

4. Tools and platforms used in Semantic Networks

The tools and platforms that will be briefly characterised in this section of the article assume a priori:

- fast and effective exchange of information,
- security in sending and receiving data,
- effective individual and team communication,
- integration with most commonly used tools,

Important tools and platforms used in Semantic Web concepts include:

- Chanty – a business communication tool that integrates chat, project management and collaboration functions in one place. It offers an intuitive interface, which makes communication within the organisation easy and effective (Chanty, 2024). Chanty is also a task management platform. With the ability to prioritise, set deadlines and share files, the team can work effectively on a project with all the necessary information in one place. Thanks to end-to-end encryption, even the most confidential conversations are protected from unauthorised access.
- Discord – a modern tool that facilitates teamwork and effective communication. It is a free application that enables voice and text communication, as well as real-time collaboration. It can be used on various platforms, including computers, smartphones and tablets, making it easily accessible to all team members, regardless of their location. Discord allows you to structure communication by using channels (Dobre Programy, 2024). This facilitates organised content management and access to all information within the organisation. Discord is a versatile messenger that works perfectly in a business environment. With voice and text communication, content structuring, integration with other tools, and data security, Discord becomes an invaluable aid in effective teamwork using the Synaptic Network structure.
- ClickUp – is a versatile project and task management system that integrates a range of features, enabling effective planning, monitoring, and execution of projects. It offers an intuitive interface that makes the platform easy to use, even for those unfamiliar with advanced technology.
- Fleep – an advanced communication and collaboration tool designed for organisations that want to optimise their business processes. Its main goal is to consolidate various forms of communication in one place, thus eliminating the chaos resulting from using multiple tools simultaneously. It allows you to create dedicated workspaces for teams that can be easily connected to project management programmes, calendars or documents. In an era of rapid technological development, tools such as Fleep are becoming indispensable for organisations wishing to keep pace with the competition (Dobrakowski, 2024).
- Flock is an advanced business communication platform that combines chat, collaboration, project management and many other features. It is a tool that enables teams to communicate and collaborate effectively in one place (Chanty Blog, 2025). Flock offers project management features, allowing teams to effectively track progress, assign tasks, and create schedules. It is an ideal tool for organisations that want to maintain control over their project management functions without the need for separate applications.

- Glip – a modern communication and project management platform that integrates chat, collaboration, planning and organisation features in one place. It is a tool designed to facilitate teamwork, regardless of whether employees are in one office or scattered around the world. It supports real-time communication, especially when an organisation operates in an environment where the speed of response to market changes can be crucial. One of the main advantages of Glip is the ability to integrate project planning directly into the tool (Dhosting, 2023).
- Mattermost is an open platform for business communication. It is a kind of "chat for organisations", but with a much wider range of functions than popular instant messengers. It allows organisations to build their own private communication servers, giving them full control over data and security (Wysocka, 2023). Mattermost platforms enable integration with many other business tools, such as project management systems, collaboration applications and task monitoring tools. It is a powerful tool for managing communication within an organisation.
- Pumble – a communication and management tool that integrates with many features and tools (e.g. Google Drive, Dropbox, and Trello) to facilitate team collaboration. It is a so-called "combo" for project management, chat, and a place to store and share files. Using various forms of management, Pumble allows you to create projects, assign tasks, monitor progress, and supervise schedules. This allows project leaders to focus on their main goals while maintaining full control over the team's current activities (Google, 2022).
- Rocket.Chat – a flexible communication platform that facilitates organisational management and streamlines communication processes, keeping pace with technological developments and the evolution of communication tools, offering modern and effective ways of exchanging information. It is a flexible tool that can be self-hosted or used in a cloud version (Rocket Chat, 2025).

5. Summary

Work is currently underway to develop the standards needed to implement the concept of *the Semantic Web*. The aim is to enable information available on the Internet to be processed not only at the level of individual characters in a text, but also taking into account the structure of the document and the concepts contained in the text. The aim is to create and disseminate standards for describing content on the Internet in such a way that it can be processed by machines and programmes, taking into account the meaning and context of the information (Folta, Stolińska, 2012). The Semantic Web is based on ontologies (Abramowicz et al., 2010) and software agents. Ontology, as a specialised conceptual apparatus, "is intended to support

and be responsible for the efficient and unambiguous exchange of information between its users". The recipients of ontology are agents operating in information systems and within the framework of the Semantic Web concept. Managers (humans) will continue to make key decisions, but agent technologies and the IT systems built using them will represent them to a certain extent (acting in an autocratic role) and will assist them in decision-making (acting in an advisory capacity). The role of agent- technologies in building an information society defined in terms of human work should be assessed in terms of contradictions (mutual contradictions, discrepancies) rather than synergies (cooperation). The situation is different when it comes to identifying the role of agent technologies in building a digital society. A key issue for the development of agent technologies is the continuation of work related to the creation of Semantic Internet standards, and in particular the popularisation of ontology as a method of knowledge representation in an IT system (Niedbał, 2015).

Abstract

This article provides a concise overview of the key issues in semantic network structures. The descriptions focus on supporting management processes, primarily during project work. The components of a semantic network operating on a set of statements used in ontological terminology have been characterised. The operation of a semantic network is presented in three stages: goal formulation, SWS search, and web service invocation. Semantic search engines based on natural association chains are presented and described comprehensively, along with the tools and platforms used in semantic networks. Software agents, indispensable in semantic network systems, are mentioned.

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AGILE METHODS OF MANAGING SERVICE FACILITIES ON THE EXAMPLE OF AN ACCOUNTING OFFICE

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Purpose: The aim of the article is to identify the ways of using agile management methods in the functioning of an accounting office and to determine their importance for the efficiency and competitiveness of a service facility.

Design/methodology/approach: The study was based on an analysis of the literature on the subject and a qualitative in-depth interview conducted with the manager of the accounting office.

Findings: The results of the research indicate that the use of agile management practices is conducive to increasing the flexibility of operations, improving the quality of services and strengthening the competitive position of the accounting office.

Research limitations/implications: The limitations of research are the use of a single case study and the lack of triangulation of research methods, which limits the possibility of generalizing the results.

Practical implications: The results obtained may be the basis for the implementation of agile management practices in other service facilities operating in a dynamic environment.

Social implications: The use of agile management methods can contribute to improving the quality of customer service and increasing the stability of relations between the accounting office and its stakeholders.

Originality/value: The value of the article lies in the extension of the application of the concept of agile management to the area of functioning of accounting offices and the provision of empirical evidence from the professional services sector.

Keywords: agile methods, management, service facilities, accounting offices, enterprise.

Category of the paper: research paper.

1. Introduction

Modern service outlets operate in conditions of growing competitiveness, market turbulence, progressive digitization and increasing customer expectations in terms of quality, timeliness and flexibility of the services provided. A special example of this type of organization are accounting offices. These facilities operate in an environment characterized by constant regulatory and legal changes and pressure to automate processes. There is also a need to respond quickly to the needs of business customers. In the light of such conditions, traditional, hierarchical management models are increasingly proving to be insufficient. This undoubtedly justifies the need to look for modern organizational approaches. One of them is agile management methods. So far, they have been widely analysed mainly in the context of projects and technological organisations, and are still relatively rarely referred to the functioning of service establishments, such as accounting offices. Taking up this issue therefore allows to fill an important research gap and expand the existing considerations on organizational agility.

The aim of the article is to identify the use of agile management methods in the functioning of an accounting office and to determine their importance for organizational efficiency and competitiveness of a service facility. The added value of the study lies in the combination of a theoretical perspective with an empirical case study. This makes it possible to better understand the practical conditions for implementing agile management practices in the accounting services sector. The article consists of several logically related parts. The first part presents the essence and specificity of agile management methods. Next, the contemporary conditions of the functioning of accounting offices, resulting from digital transformation and the change in the role of the accountant, were discussed. The next part is devoted to the methodology of empirical research, including a qualitative in-depth interview with the person managing the accounting office. In the next part, the results of the research are presented and interpreted. At the same time, the key practices of agile management and their importance for the competitiveness of the office were indicated. The article was concluded with a discussion on the results of the study. Conclusions were then formulated, including practical recommendations, limitations of research and directions for further analysis.

1.1. Specificity of agile management methods

Agile management methods in modern market conditions are becoming an effective response of organizations to the growing complexity, uncertainty and increased and turbulent pace of changes taking place in the market environment. In the literature on the subject, it is emphasized that the agile approach goes beyond the framework of project management. In addition, it increasingly covers entire models of organizational management, including process structure, decision-making, and stakeholder relationships (Kohnová et al., 2023;

Wiechmann et al., 2022). Organizational agility enables modern organizations to respond faster to technological and market changes. This is what helps maintain competitiveness, especially in the conditions of digital transformation and pressure on operational efficiency (Kadenic, Tambo, 2023; Ferreira, Nobre, 2022). In this approach, agile management methods become a derivative of the concept of dynamic capabilities. They allow organizations to adapt to change. They can also actively use them as a source of competitive advantage.

The literature on the subject clearly indicates both the benefits of using agile management methods, such as better quality of results, greater transparency of processes and faster delivery of value, as well as the challenges related to scaling agile practices, managing scope and changing organizational culture (Santos, de Carvalho, 2022; Marnada et al., 2022; Sharma et al., 2022). The importance of proper requirements management and the selection of agile methods and frameworks, such as Scrum or Extreme Programming, depending on the specifics of the project and organization is also emphasized (Tomaselli et al., 2025; Akhtar et al., 2022; Ćirić Lalic et al., 2022). At the same time, attention is paid to the role of human factors. This is where the quality of teamwork, motivation and creativity becomes of particular importance, which significantly determine the effectiveness of implementing agile management methods (Agbejule, Lehtineva, 2022; Olszewski, 2023; Ali et al., 2023).

Increasingly, agile management methods are also being analysed in the aspect of non-technological sectors. This confirms their universal character. Research on healthcare, hospitality, education, sports and construction indicates that flexibility, iterativeness and a focus on customer value are conducive to improving service quality, organizational resilience and sustainable development (Saleh et al., 2024; Mehrotra et al., 2025; Cojocaru et al., 2022; Jethva, Skibniewski, 2022; Chathuranga et al., 2023). The use of agile methods is also observed in the management of technology transfer and business processes based on cloud solutions. This fact undoubtedly further reinforces their importance in modern management models (Martin, 2023; Bitkowska et al., 2022; Sarhadi et al., 2022). In conclusion, the analysis of the literature on the subject clearly indicates that agile management methods are an important direction for the development of modern organizations. It is a process independent of the industry or scale of activity.

1.2. Functioning of accounting offices

In the last decade, the functioning of accounting offices has undergone significant transformations. The main determinant of the changes has become the progressive digital transformation. Research indicates that digitization modifies both the tools used in accounting and affects the very nature of accountants' work and the range of services provided (Sabuncu, 2022; Gonçalves et al., 2022). Automation of accounting processes, development of IT systems and data integration are conducive to increasing the operational efficiency of accounting offices. In addition, they allow for a shift in emphasis from record-keeping activities to

analytical and advisory activities (Coman et al., 2022). The literature also emphasizes that the digitization of accounting is becoming an element of customer business process management. This reinforces the role of accounting offices as partners supporting economic decision-making (Potryvaieva et al., 2022).

Changes in the functioning of accounting offices are directly reflected in the growing competence requirements for accountants. Technological knowledge, readiness to work in the digital environment and the development of transversal competences are of integral importance here. The latter include communication, data analysis, and problem-solving (Taib et al., 2022; Carvalho, Almeida, 2022). At the same time, the development of advanced technologies, including blockchain-based solutions, opens up new perspectives for the security, transparency, and credibility of financial information. In the long term, this may significantly affect the operating models of accounting offices (Garanina et al., 2022). This change is also conducive to the evolution of the role of the accountant, whose role is evolving towards a business partner and advisor in the area of risk management. Building organizational resilience of customers is also crucial. This is one of the key directions for the development of modern accounting services (Tillema et al., 2022).

2. Methods

The aim of the research was to identify the use of agile management methods in the functioning of an accounting office and to determine their importance for organizational efficiency and competitiveness of a service facility. A research hypothesis was adopted, according to which it was assumed that the use of agile management practices in an accounting office is conducive to increasing the flexibility of operations, improving the quality of services provided and strengthening the competitive position of the organization in a turbulent market environment.

Research questions were posed that related to the identification of the most important challenges in accounting office management, ways of making operational decisions, organization of teamwork, the role of internal communication and the importance of IT tools in shaping organizational agility. In the course of the study, it became appropriate to determine how agile management practices affect the quality of services and the formation of relationships with customers. The research method used was a qualitative in-depth interview. It was carried out with the person managing the accounting office - the "Sokalscy" Tax Advisory Office, which provides comprehensive accounting, tax and advisory services for enterprises. This person was deliberately chosen to conduct the interview, due to his decision-making function and direct influence on the organization of processes and the strategy of the institution. The interview was partially structured. Its aim was to identify management practices that

correspond to the assumptions of agile management methods in service facilities. The "Sokalscy" Tax Advisory Office is a civil partnership of tax advisors: Bartłomiej Sokalski and Renata Sokalska.

For the purposes of this study, the concept of organizational agility was operationalized by identifying four analytical dimensions derived from the empirical material: decision-making flexibility, the iterativeness of management processes, continuity of internal communication, and the use of digital tools and automation. These dimensions constituted the basis for the qualitative analysis and enabled a structured interpretation of the obtained results.

3. Results

During the interview, they were asked about the most important challenges that arise in the process of managing an accounting office. It was taken into account that the audited entity had to operate in turbulent business conditions and frequently changing legal and tax regulations (Table 1). The respondent indicated that the key problem is the need to constantly monitor legislative changes and quickly implement them into everyday operational practice. This is what requires a flexible approach to work organization and constant improvement of the team's competencies. It was emphasized that the stability of processes must go hand in hand with readiness to modify them, which is particularly evident in periods of intensive changes in regulations.

Further questions concerned the way decisions are made regarding changes in internal processes. The response indicated that these decisions are made in an iterative manner, based on an ongoing analysis of the workload, the quality of the services provided and feedback from customers. It is noted that the changes are tested to a limited extent. Then they remain corrected depending on the results obtained.

An important problem that was raised in the interview was the organization of teamwork. The respondent indicated that work in the office is based on short cycles of task planning and regular evaluation of their implementation. This makes it possible to react quickly to delays or unforeseen difficulties. This approach is conducive to ongoing control of work progress and reduces the risk of error accumulation.

With regard to internal communication, the importance of direct and frequent contact between team members was emphasized. The respondent noted that key information is provided on an ongoing basis, both in the form of team meetings and with the use of IT tools supporting the management of documentation and tasks. This allows for quick problem solving and better coordination of activities.

When asked about the method of monitoring the quality of services, the respondent indicated that it is based both on internal control of the correctness of the tasks performed, as well as on the analysis of comments and questions submitted by customers. As for the process of identifying errors, it is here that immediate corrective actions are taken, and the conclusions from the situations are used to improve internal procedures.

An important element of accounting office management, indicated in the interview, is the use of IT tools that support flexibility of operation. The respondent emphasized that the digitization of accounting processes and the automation of selected activities allow for shortening the time of task completion. The result is also better adaptation to the changing needs of customers. In the analysis of the results, a distinction was made between routine digitalization practices and agile management mechanisms. Digitalization refers to the automation of operational activities, whereas agility relates to the way work is organized, decisions are made, and responses to change are implemented.

Table 1.

Results of a qualitative interview - agile management of an accounting office

Question	Answer	Importance for competitiveness
What is the main challenge in office management?	Frequent changes in regulations	Enforces quick response and up-to-date services
How are operational decisions made?	Based on the current situation	Allows flexible adaptation to customer needs
How is the work of the team organized?	In short task cycles	It increases timeliness and reduces errors.
How does internal communication work?	Directly and digitally	Improves coordination and speed of service
How is the quality of service monitored?	Up to date	Builds trust and stability in customer relationships
What role do IT tools play?	Support automation	Reduce costs and increase efficiency
How does the office react to legal changes?	Immediate implementation	Provides compliance and information advantage
What is the effect of the agile approach?	Greater flexibility	Strengthens the competitive position of the office

Source: Own study.

In conclusion, the respondent assessed that the use of agile management methods is conducive to increasing the efficiency of the accounting office's functioning, improving the quality of services and building long-term relationships with clients. At the same time, it was pointed out that the implementation of such an approach requires the continuous involvement of the management and the readiness of the team to adapt and learn.

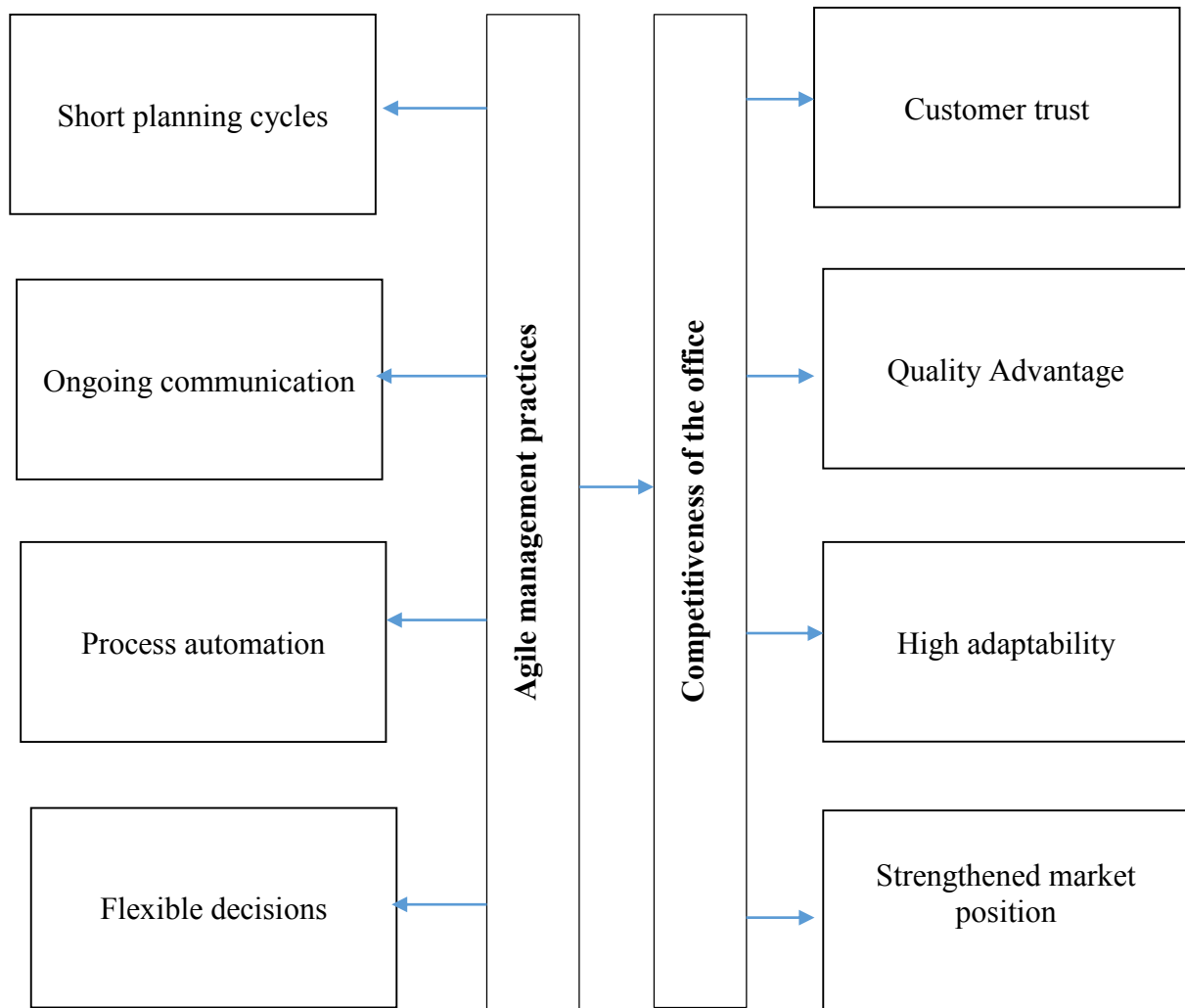


Figure 1. Agile management practices and office competitiveness.

Source: Own study.

Figure 1 presents the author's conceptual model of the relationship between the use of agile management practices and the competitiveness of an accounting office. It shows how the management methods used, such as short planning cycles, ongoing communication, process automation and flexible decision-making, translate into key organizational outcomes, including customer trust, quality advantage, high adaptability and a strengthened market position of the office. This model highlights the cause-and-effect relationship between managerial agility and an organization's ability to maintain and strengthen competitiveness in a dynamic service environment.

4. Discussion

On the basis of the conducted qualitative research, it is possible to formulate conclusions regarding the importance of agile management methods in the functioning of an accounting office. The results obtained indicate that managerial agility is an important factor that translates into the effective functioning of an organization in conditions of high volatility of the legal and tax environment and growing customer expectations.

In particular, it was confirmed that the use of short planning cycles, iterative decision-making and ongoing monitoring of the tasks performed is conducive to increasing the operational flexibility of the office. This approach allows for an immediate response to legislative changes. In addition, it reduces the risk of delays and errors in the implementation of accounting and consulting services.

An important conclusion from the research is also the need to ensure efficient internal communication. The office should also put emphasis on the use of IT tools to support team management. Digitization and automation of processes are conducive to improved efficiency and at the same time strengthen the organization's ability to quickly adapt to changing customer needs. As a consequence, this leads to an improvement in the quality of the services provided. The trust of recipients also increases.

The analysis of the results also indicates that agile management practices have a direct impact on the competitiveness of an accounting office. A flexible approach to management, based on an ongoing analysis of the situation and quick implementation of changes, is conducive to building a quality advantage and strengthening the market position of the organization. At the same time, it was emphasized that the effectiveness of this approach depends on the constant commitment of the management and the readiness of the team to learn and adapt.

The results of the research presented in the analyzed article are consistent with the findings of other researchers dealing with the issue of organizational agility in the service sector. In particular, they correspond to the conclusions of Ferreira and Nobre (2022). These authors have shown that agile management practices, embedded in the logic of dynamic capabilities, are conducive to increased operational flexibility. They also contribute to a more effective response of the organization to the variability of the environment. Similar relationships are identified by Wiechmann et al. (2022). They indicate that iterative decision-making, ongoing communication and the use of digital tools strengthen the competitiveness of small and medium-sized service enterprises in the conditions of digital transformation. In turn, the findings of Coman et al. (2022) confirm that the emphasis on the development of digitization increases the efficiency of accounting offices. The introduction of digital tools is conducive to improving the quality of services and building customer trust. Thus, the results obtained confirm the legitimacy of the implementation of agile management methods in

organizations providing professional services. It should be noted, however, that transferring agile management frameworks, originally developed in project-based contexts, to standardized service processes such as accounting involves significant limitations. These stem from the high degree of formalization, regulatory constraints, and repetitiveness of activities.

5. Conclusions

On the basis of the formulated conclusions, recommendations for service companies can be made. It is recommended to implement agile management practices as a permanent element of the organization's functioning. Particular importance should be given to short cycles of planning and evaluation of the tasks carried out. They allow for ongoing adaptation of processes to changing legal and market conditions. It is also recommended to develop an organizational culture conducive to open communication and a rapid flow of information. This can reduce the risk of operational errors and increase team consistency.

At the same time, it is reasonable to systematically invest in IT tools supporting the automation and digitization of service processes, while improving the competences of employees in their use. This approach is conducive to increasing operational efficiency, improving the quality of customer service and building a sustainable competitive advantage. It is also recommended that the management consistently monitor the effects of the implemented solutions. Hence the conclusion that management should treat organizational agility as a process of continuous learning and adaptation.

The conducted studies encountered some limitations that should be taken into account when interpreting the results obtained. The analysis was based on a qualitative in-depth interview conducted with one respondent. This fact limits the possibility of generalizing applications to the entire population of service establishments or accounting offices. In addition, the subjective nature of qualitative data, resulting from the individual perspective of the manager, may affect the perception of the practices used and their effectiveness. Another limitation is the lack of triangulation of research methods. In particular, the limitation is the lack of supplementing qualitative research with quantitative analysis or the perspective of employees and customers. The combination of these methods could deepen and verify the results obtained.

In future studies, it would be reasonable to expand the analysis to include more service establishments and to use a mixed approach, combining qualitative and quantitative methods. Taking into account the perspective of employees and customers would allow for a more complete assessment of the impact of agile management methods on the efficiency and quality of services. A long-term analysis, on the other hand, would make it possible to identify the lasting effects of organizational agility in the context of competitiveness.

In the short term, the application of agile management principles contributes to streamlining operational processes, improving timeliness, and enhancing service quality. In the long term, agility constitutes a factor that strengthens an organization's adaptive capacity and supports the development of a sustainable competitive advantage for professional service firms.

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IMPACT OF GENDER DIVERSITY OF THE BANK'S MANAGEMENT BODY ON BANK'S PERFORMANCE AND RISK

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Purpose: The aim of this paper is to investigate whether there is a relationship between gender diversity and bank efficiency and security in the context of EU regulations stipulating that a more diverse executive board structure should monitor the governance and supervisory process more effectively in terms of enhancing the institution's resilience to risk factors.

Design/methodology/approach: The subjects of the analysis were commercial banks registered in the form of a joint stock company in Poland, Germany and France between 2018 and 2021. The results of the study on ROA and TCR were correlated with the author's coefficient of gender diversity of banks' management bodies.

Findings: The results demonstrate that as market uncertainty increased (in this case as a result of the Covid-19 pandemic), banks with a higher degree of management diversity generally performed worse. In contrast, a higher degree of management diversity before the Covid-19 pandemic had a positive or neutral impact on TCR levels, but as the pandemic erupted, TCR increased, regardless of the degree of bank management diversity.

Research limitations/implications: Future research should include the concept of neurobanking, which may prove helpful in reducing human risk in banks.

Practical implications: The findings provide that gender diversity of banks' management bodies does not have the effect of improving the efficiency of banks' operations and their security.

Social implications: The results of the research do not unequivocally show that a higher degree of diversity in banks' management bodies is a reliable way of solving the problems of increasing the efficiency of banks' activities and their security at the same time. Even the introduction of penalties for banks with insufficiently diverse management bodies by banking supervision will not eliminate the risky behavior of individuals whose actions are determined by the structure of their central nervous system.

Originality/value: This study introduces a novel perspective by examining the impact of gender diversity of the bank's management body on banks' performance and risk. The analysis is relevant both to researchers in finance theory and to practitioners involved in developing security rules for banks.

Keywords: banks, gender diversity, executive board structure, financial efficiency, total capital ratio, Covid-19.

Category of the paper: Research paper.

1. Introduction

The gender diversity of management bodies, including those of financial institutions, has been subjected to numerous studies in recent years. Many of them show a positive impact of gender diversity on company performance (Martin-Ugedo et al., 2019; Prashar, Gupta, 2020), while others show no evidence of a correlation between gender diversity and company performance (Vairavan, Zhang, 2020). In contrast, research by Khan et al. (2021) suggests that only gender balance in executive board structures can improve the company performance. Although gender diversity of management bodies is a topic in dispute, it has attracted the attention of not only academics but also legislators (Song et al., 2020).

Culture related factors that determine the behavior of bank employees, such as individualism or attitude to risk, are important elements which affect bank corporate culture, and – indirectly – the scale of risk taken by the bank. Corporate culture is also affected when ownership supervision is vested in natural persons who are members of the same family. In the case of banking sector, the so-called family businesses play a much less important role than in other economy sectors as they are mostly limited to small or niche banks (e.g. offering only private banking services). Nonetheless, even such banks are considerably different in terms of corporate culture as compared to large banks which operate in the form of joint stock companies and are listed on regulated markets (El Ghouli et al., 2016). The main difference involves much greater reputation concerns typical of the banks run by family members. This has a direct impact on planning. Family-owned banks are not bound by the time limits imposed by the term of office of statutory bodies while any modifications to the bank profile or its policy are correlated with generational changes.

Cultural factors which determine employees' conduct in different countries are highly important as they represent potential sources of systemic risk and also influence the course and scale of crises. During the last global financial crisis, banks in the countries where populations have strong aversion to risk and greater power distance achieved relatively better results. On the other hand, banks in individualist societies performed worse during the crisis, which was due to the fact that such communities promote individual achievement, self-orientation, focus on goals and efficiency (Boubakri et al., 2017). We can therefore conclude that cultural factors such as low aversion to risk and focus on individual achievement are important sources of risk involving long-term impact. It may take a generational transformation to change these factors, which may last even several decades. The above cultural factors are key to the banks operating mainly in their home countries. Global banks are exposed to them to a much lesser degree, which is due to their presence in many countries of different national cultures but also to a multi-cultural composition of their management bodies. Moreover, owing to their systemic importance, global banks have to comply with additional regulatory requirements, which decreases their flexibility and susceptibility to the national culture impact (Mourouziidou-

Damtsa et al., 2019). It specifically refers to global European banks of systemic importance, which are monitored and supervised directly by the European Central Bank. Nonetheless, cultural differences should be taken into consideration both in the strategies adopted by global banks and in the examination of individual banks' situation performed by financial security network institutions (Ashraf et al., 2016).

In highly developed countries, the composition of management bodies, which is related to the corporate culture model adopted in a given country, has a considerable impact. In particular, the level of management bodies autonomy, including the number of their members, duration of the CEOs' terms of office and even gender diversity (Ahmadi et al., 2018). An interesting example was given in the study on the importance of gender of bank CEOs in terms of risk level in the institution they run. One of the studies was based on a sample of Polish cooperative banks. It showed that cooperative banks run by women have better capital adequacy and own funds to assets ratio. Credit risk level in the banks run by women is not different from credit risk level in the banks managed by men, while greater capital adequacy does not result from lower asset quality and is most probably connected with stronger aversion to risk among female CEOs (Skała, Weill, 2018). However, the studies on the influence of banks' management bodies with greater gender diversity, carried out in the USA, have shown that the increase in the number of women members of management bodies improves their results provided that an adequate level of diversity is achieved and that a bank has high capital ratios (Owen, Temesvary, 2018).

In accordance with current European regulations, the key role in ensuring balance in a bank management body in terms of knowledge, skills, diversity and experience is played by a nomination committee. His tasks include, among others deciding on a target for the representation of the underrepresented gender in the management body as well as preparing a policy on how to increase the number of the underrepresented gender in the management body in order to meet that target. In performing its duties, the nomination committee shall, to the extent possible and on an ongoing basis, take account of the need to ensure that the management body's decision making is not dominated by any one individual or small group of individuals in a manner that is detrimental to the interests of the institution as a whole (Directive 2013/36/EU).

EU regulations also stress the role of non-executive directors and independent supervisory board members, whose activity may not only improve management quality and the results achieved by individual banks but it may also reduce risk. Mere independence and adequate qualifications and experience demonstrated by these persons may not be sufficient as long as adequate mechanisms and procedures are not established to ensure that these can have effective influence on the bank's situation (Siclari, 2015). In particular, it is necessary to ensure that they are part of the integrated risk control and risk management system. A bank body, which includes such members, must be responsible for strategic supervision and for defining a business model of the bank. Control mechanisms in banks should involve diverse knowledge and experience of qualified experts (Thuiner, 2015).

2. Research problem

The literature review has shown that there is little analysis of the topic of gender diversity of banks' management bodies and its impact on bank security and efficiency. Therefore, the aim of this thesis is to investigate whether there is a relationship between gender diversity and bank efficiency and security in the context of EU regulations stipulating that a more diverse executive board structure should monitor the governance and supervisory process more effectively in terms of enhancing the institution's resilience to risk factors. In addition, an attempt was made to verify whether the gender diversity of the bank's management body had an impact on risk and efficiency performance during the period of both economic stability and instability caused by the Covid-19 pandemic.

The considerations undertaken in this article included the questions as follows, i.e.: 1) What is the level of gender diversity of banks' management bodies in three given European Union countries?; 2) Did the instability caused by the Covid-19 pandemic increase the diversity of bank management bodies?; 3) Does greater diversity of banks' management bodies result in greater bank efficiency?; 4) Does greater diversity of bank's management bodies guarantee greater bank security?; 5) What other tools can contribute to reducing human risk in the banking sector?

3. Data and sample

In order to answer these questions, required data were obtained from 54 commercial banks registered in the form of joint stock companies in Poland (25), Germany (16) and France (13). The definition of the research sample including banks from these countries was the result of a desire to compare the performance of banks in Poland to banks from leading European Union countries, i.e. from Germany and France. However, due to the great diversity of banking sectors in the selected countries (for example, in Germany many banks operate in the form of a limited liability company or are public credit institutions, such as Landesbank or Sparkasse), the criterion for selecting the research sample was registration in the form of a joint stock company. The research period covered years between 2018 and 2021. The adoption of such a research period was driven by the desire to test whether a period of stability or instability in the economy affects the gender diversity of banks' management bodies and whether greater diversity in times of instability results in better performance in terms of bank efficiency and security. The required data were taken from published annual financial statements for 2018, 2019, 2020 and 2021. The dataset included: total capital ratio, net profit, own funds, total capital requirements and the number of women and men on the bank's executive board. None of the

individuals included declared themselves to be non-binary or of a gender other than female or male.

Originally, the database of entities surveyed consisted of 61 banks (30 Polish, 18 German and 13 French). In the course of data acquisition, five Polish banks and two German banks were excluded from the database due to, among others, missing individual data and ongoing liquidation proceedings. Of the Polish banks, Bank Nowy SA, Idea Bank SA, ING Bank Hipoteczny SA, Mercedes-Benz Bank Polska SA and Millennium Bank Hipoteczny SA were removed from the database. As for German banks, ING DiBa and J.P. Morgan AG were also removed. The final list of banks can be found in the appendix.

4. Methods

The following measures were used to determine the level of efficiency and security of the banks under study:

- Return on Assets (ROA) [%] representing the quotient of net profit and total assets.
- Total Capital Ratio (TCR) [%], which is the quotient of own funds and total capital requirements.

The gender diversity of the bank's management board was determined in Equation (1) on the basis of the bank's gender diversity ratio, which was defined as the number of persons of the less represented gender related to the total number of persons on the board.

$$\text{diversity ratio} = \frac{\min(N_w, N_m)}{N_w + N_m} \times 100 \quad (1)$$

where:

N_w – number of women in the management body,

N_m – number of men in the management body.

The value of the diversity ratio can range from 0 to 50, where 0 means no gender diversity at all in the bank's management body (the entire executive board is composed exclusively of people of the same gender) and 50 means full diversity (the same number of men and women in the management body). The entities were grouped on the basis of the results obtained for the diversity ratio due to the significant diversity of the banks. Three diversity ratio ranges were defined, i.e. <0-16> - low diversity; <16-33> - medium diversity; <33-50> - high diversity. The results obtained are presented in Figures 1-3 and interpreted accordingly.

5. Results and discussion

The first part of the study analyzed the scale of diversity in terms of gender of the surveyed bank management bodies. According to the research conducted in Poland, in the pre-pandemic period, only 32-36% of bank management bodies were characterized by a diversity index exceeding 16, of which only among 16% of entities had the diversity index of at least 33. As many as 64% of the surveyed banks had a low diversity index (below 16). It was not until 2020 that the diversity of Polish banks' management bodies increased, resulting in a diversity ratio of <33-50> in 28% of the banks surveyed and <16-33> in 24% of the banks in question.

In 2021, the degree of banks' management bodies diversity in Poland followed a similar pattern to the one from 2020, although there was a 4 p.p. lower level of large in favor of small diversity. The above analysis therefore shows that the market instability caused by the Covid-19 pandemic resulted in a higher level of gender diversity for banks in Poland than in the pre-pandemic period (Figure 1).

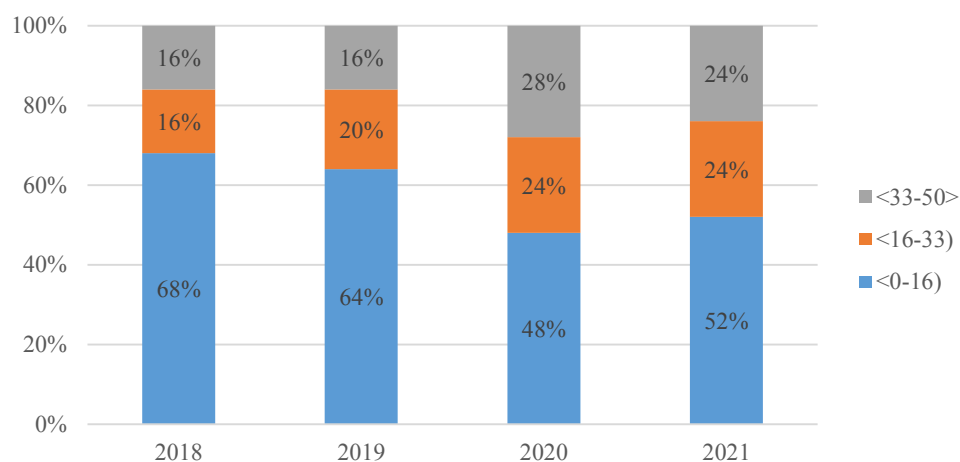


Figure 1. The diversity ratio of banks in Poland between 2018 and 2021.

Source: Own calculations.

When analyzing the data from German and French banks, there is no significant similarity in the degree of management diversity in the two countries. The greatest management diversity was observed in the French banking sector. For 38% of the banks surveyed in 2018, 2019 and 2021, the level of management diversity was highest, i.e. in the third range <33-50>. The lowest level of diversity was observed in 2018, when it was in the <0-16> range in 38% of French banks. In the following two years, the number of banks in this range gradually decreased, although it increased again in 2021, when 23% of banks had the lowest degree of gender diversity in their executive board structures (Figure 2).

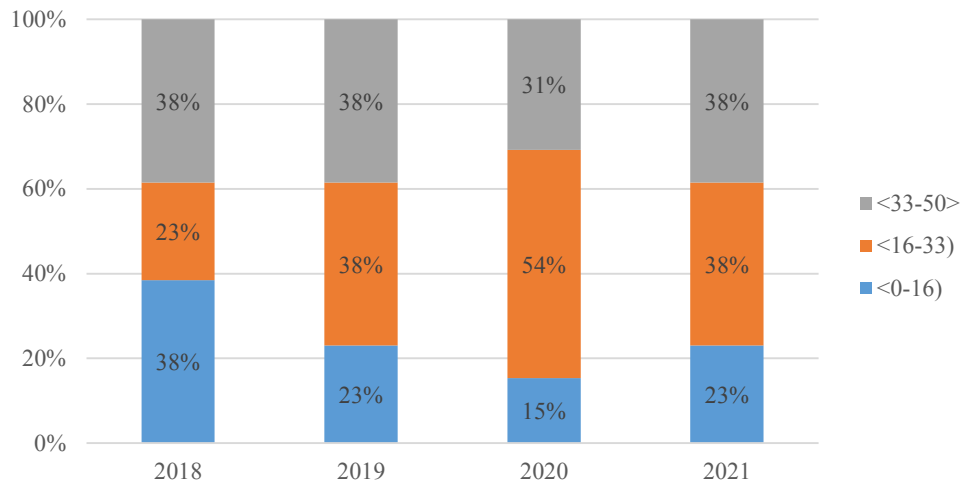


Figure 2. The diversity ratio of banks in France between 2018 and 2021.

Source: Own calculations.

In the German banking sector, on the other hand, the lowest degree of management diversity was observed among as many as 63% of banks in 2018 and 56% in the following three years. The range of the second diversity factor in the year immediately before and during the pandemic included the fewest surveyed German entities (19% in 2019 and 13% in 2020, respectively), and in 2021, a significant increase in the number of banks was observed in this range - up to 38% (this range included, among others, the three largest banks in Germany (Figure 3).

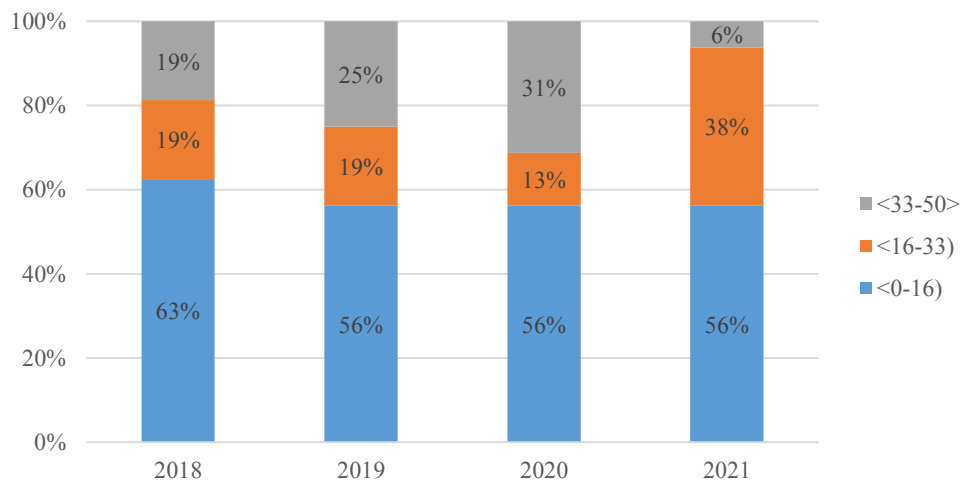


Figure 3. The diversity ratio of banks in Germany between 2018 and 2021.

Source: Own calculations.

In terms of the gender diversity of the management bodies, Polish banks rank similarly to those in the German banking sector compared to the two Western sectors surveyed. However, a relatively slow trend of increasing diversity can be observed in both sectors.

Another object of the analysis was to try to find a relationship between the yield of bank assets and the diversity ratio in each of the three banking sectors studied.

In the Polish banking sector in the years leading up to the Covid-19 pandemic, banks with lower management diversity had a higher yield of assets. The Covid-19 shock, the huge uncertainty in the market and the government's decisions to help the real economy resulted in a decline in the ROA of banks in each diversity range. However, among the banks with the highest degree of diversity, the lowest (negative) performance was observed in 2020, while the group of banks in the second diversity group saw negative ROA in 2021. Only the banks with the lowest degree of diversity did not record negative results during the Covid-19 pandemic. It can therefore be concluded that higher levels of management diversity were generally associated with lower bank efficiency (Figure 4).

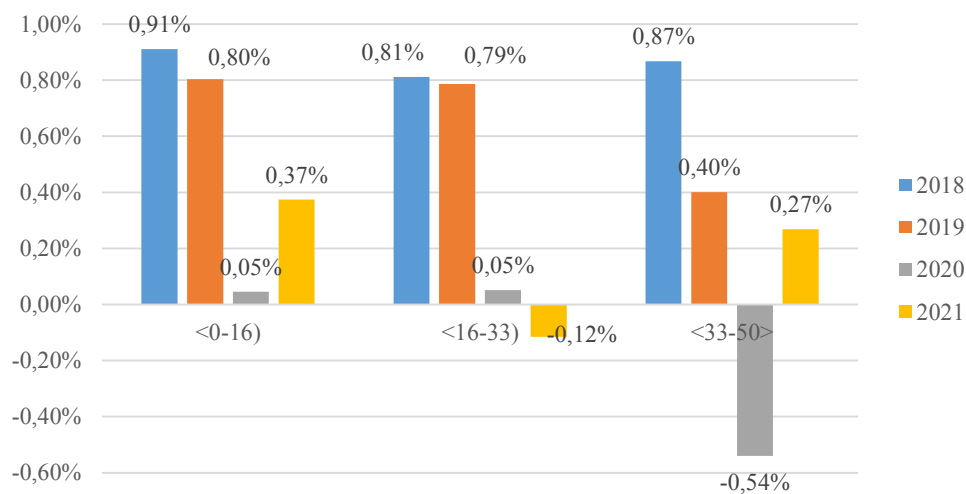


Figure 4. ROA of Polish banks by diversity ratio between 2018 and 2021.

Source: Own calculations.

Such a relationship was also observed in the case of French banks. During the study period, banks with a lower level of management diversity achieved the highest level of ROA (Figure 5).

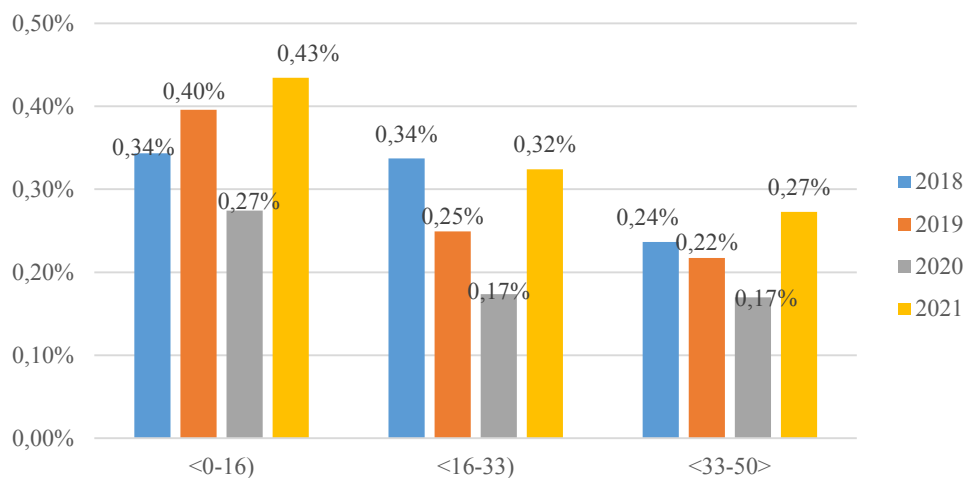


Figure 5. ROA of French banks by diversity ratio between 2018 and 2021.

Source: Own calculations.

In contrast, in the pre-pandemic period, German banks with a degree of diversity of 16 and above showed higher management efficiency, while during the pandemic higher efficiency was achieved by banks with a lower or medium degree of board diversity (Figure 6).

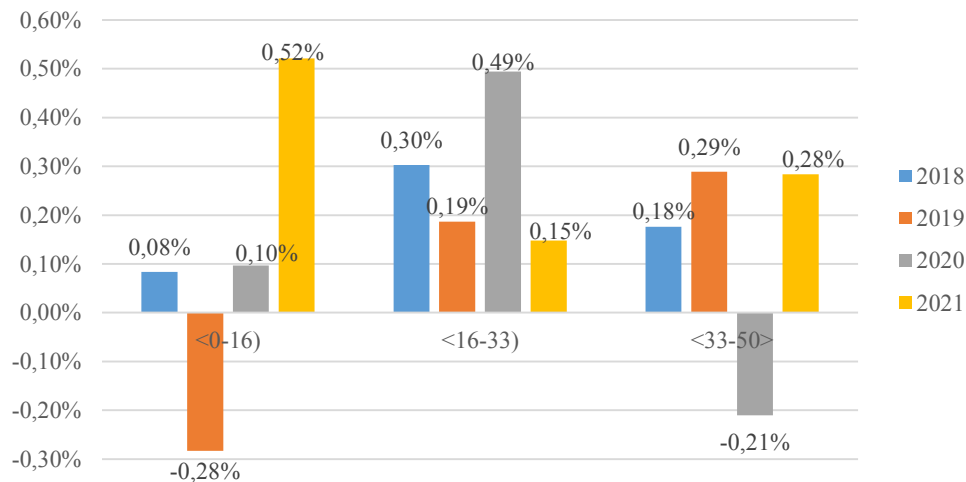


Figure 6. ROA of German banks by diversity ratio between 2018 and 2021.

Source: Own calculations.

When comparing the relationship between the profitability of bank assets and the degree of management diversity of all banks studied, it was observed that as market uncertainty increased (in this case as a result of the Covid-19 pandemic), banks with a higher degree of management diversity generally performed worse.

The final object of the analysis was to see whether higher levels of management diversity improve bank security. The results of the study showed that only in the case of German banks, those with the highest level of Total Capital Ratio were the ones with the highest degree of management diversity (Figure 7).

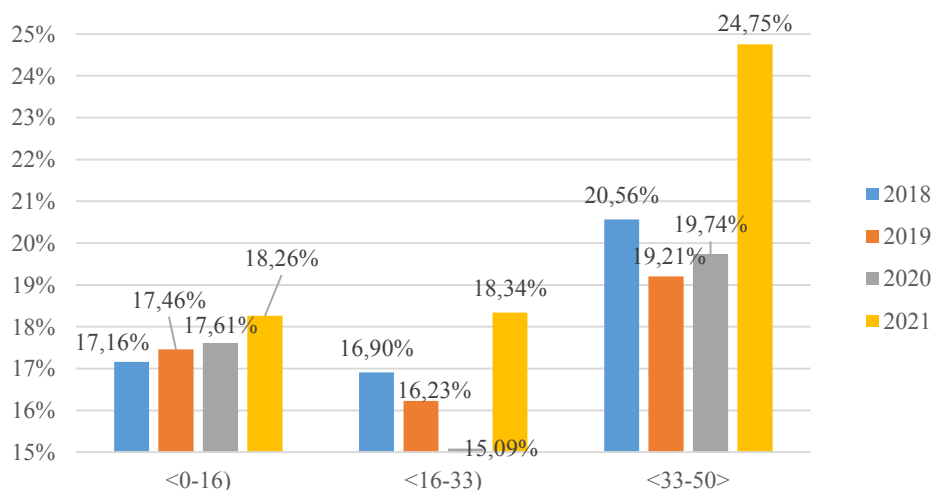


Figure 7. TCR of German banks by diversity ratio between 2018 and 2021.

Source: Own calculations.

For French banks, a similar situation, i.e. the highest level of Total Capital Ratio shown by banks with the highest degree of management diversity, occurred only before the pandemic. Indeed, with the outbreak of the pandemic, it was the banks with the lowest degree of diversity that reached the highest levels of Total Capital Ratio (Figure 8).

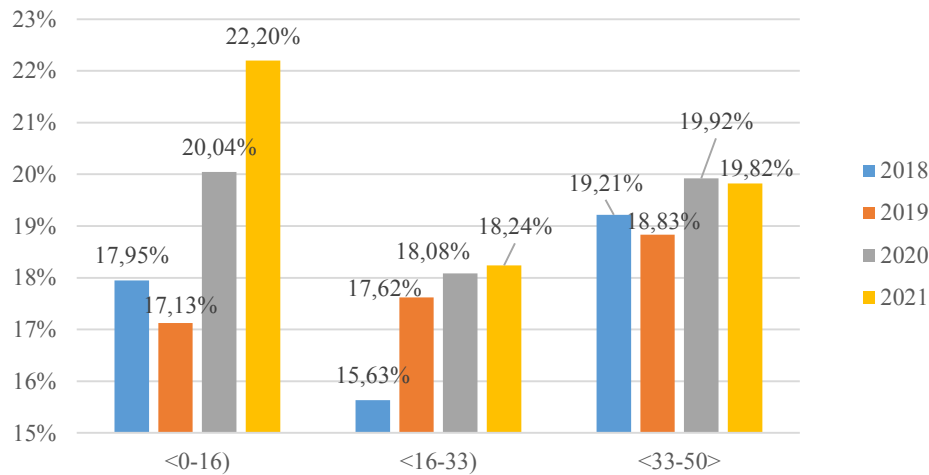


Figure 8. TCR of French banks by diversity ratio between 2018 and 2021.

Source: Own calculations.

The case of Polish banks, on the other hand, is quite ambiguous. Within this group of banks, the banks with the highest levels of Total Capital Ratio were those with the highest levels of diversity (2019 and 2021) or those with the lowest levels of diversity (2018 and 2020). Nevertheless, the small differences between the levels of Total Capital Ratio in Polish banks allow us to conclude that it practically does not depend on the degree of gender diversity of banks' executive board structures (Figure 9).

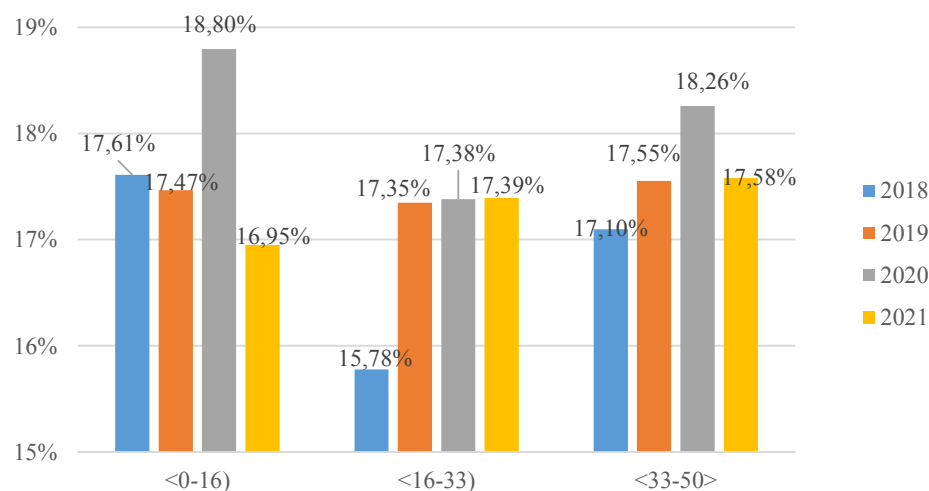


Figure 9. TCR of Polish banks by diversity ratio between 2018 and 2021.

Source: Own calculations.

At the same time, it is worth noting that in the first year of the pandemic (2019), the Total Capital Ratio increased in all surveyed banks regardless of the degree of diversity (with the exception of German banks with a medium degree of management diversity). In summary, it can therefore be concluded that a higher degree of management diversity had a positive or neutral impact on the TCR level before the pandemic, while with the outbreak of the pandemic the TCR increased regardless of the degree of management diversity of the banks. Only the example of the German banking sector proves that a higher diversity guarantees a higher security of banks, regardless of the circumstances.

The analysis carried out and the results of the research do not conclusively show that a higher degree of diversity in bank management is a reliable way of solving the problems of increasing the efficiency of banks' operations or their security.

6. Gender diversity of the bank's management body is not enough

Diversification on bank's management body although fully reasonable – may not be considered as instruments which will help us effectively solve the problem of human risk in the banking sector. Even a system of penalties imposed on the banks with not diversified management bodies, will not eliminate risky behavior of certain individuals, determined by the structure of their central nervous system (Koleśnik, 2022).

The research has shown that in terms of reducing human risk in the process of bank risk management, in order to measure risk propensity, the desired level of reaction of the nucleus accumbens (part of the striatum in the brain) should be defined. More intense activity of this brain area occurs when an individual expects a financial benefit. It should be also noted that this measure would refer both to risk propensity in the case of expected profit amounts and to the occurrences involving extraordinary profit. Its level would provide us with a specific greed threshold since a person whose activity of the nucleus accumbens is below this threshold would not be prone to the temptation of taking a greater risk only because in the past a similar event or operation accidentally generated a high risk. Expectation of increasing rewards (profit) intensifies the activity (oxygenation) of the nucleus accumbens, which, on the other hand, is not provoked by the prospect of greater punishment (loss) (Knutson et al., 2001a). Results of other studies confirm that making decisions which can lead to earning a profit or incurring a financial loss is also connected with the activity of other brain areas. It was also shown that the fact which brain area becomes more active depends both on whether we expected a profit or a loss and on the final result (Table 1).

Table 1.*Brain areas active depending on the profit earned or loss incurred*

Brain area	Profit		Loss	
	realized	non-realized	realized	non-realized
Orbitofrontal cortex			X	X
Anterior cingulate cortex			X	
Ventral striatum		X		X
Dorsal striatum	X			
Insula	X		X	
Thalamus	X		X	

Source: Wrase et al., 2007.

It should be noted that some of the brain areas are activated in more than a single situation, as shown in Table 1. Structures such as the insula, thalamus and medial prefrontal cortex were found to be particularly active in the decision-making processes which resulted in profit or loss (Knutson et al., 2000). Other studies found centers of activity in the ventral striatum and in the forebrain as well as some differences in the activity of these areas depending on whether the expected profit was realized or not (Knutson et al., 2001b).

In terms of reducing human risk using the concept of neurobanking, it is essential that – despite very promising results of the abovementioned studies – certain processes occurring in the central nervous system (CNS) are more complex and the current knowledge is not sufficient to provide a precise neurological model of individuals responsible for risk management in the banks.

Nevertheless, a new, long-range trend to reduce human risk in banking should be based on the concept of neurobanking, which should include a definition of neurorisk, i.e. a risk resulting from the pathology of certain structures of the CNS in individuals managing the bank. Taking into account the progress of neurological research devoted to finance (Ruff, Huettel, 2014), neurobanking could be seen as an emerging sub-domain of banking, and not only as one of the numerous analytical approaches. Neurobanking should therefore become a sub-domain of banking, dealing with the influence of the structure and functioning of the human CNS on the security of individual banks and the entire banking system (Flejterski, 2009). It should aim to identify the CNS structures which are responsible for increased propensity to take risk in banking and to develop a neurological model of people responsible for the level of risk run by the bank. Presented in such a way, the concept of neurobanking may be challenged on the grounds of possible discrimination of people whose CNS will not meet certain criteria. This objection, however, seems invalid if we look at the consequences which may arise when the most important risk management decisions in banking are taken by people whose anatomic structure and functioning will naturally make them more inclined to take action which involves greater risk. A clearly defined model of CNS structure would be a development of medical models which are now applied e.g. in aviation. The concept of neurobanking will therefore make it possible to fully respect the rule that the banking supervisory bodies have long shared, which claims that individuals managing banks, especially those responsible for risk, must guarantee due performance of their duties (Koleśnik, 2011).

7. Conclusion

The considerations undertaken in this article were to test whether there is a relationship between the gender diversity of banks' executive board structures and their efficiency and security, and whether greater management diversity in times of instability results in better bank efficiency and security outcomes.

The research conducted on a sample of 54 banks from Poland, Germany and France shows that the degree of management diversity in each of the three sectors is different. The highest management diversity was observed in the French banking sector, while the lowest in the German sector. In terms of management diversity, Polish banks rank at a similar level to those in the German banking sector when compared to the two leading EU banking sectors. In both cases, a trend of increasing banks' management diversity was noted, albeit relatively slow. The market instability caused by the Covid-19 pandemic increased the degree of diversity in each of the banking sectors studied.

Comparing the relationship between the yield of bank assets and the degree of management diversity of all the banks studied, it was noted that as market uncertainty increased (in this case caused by the Covid-19 pandemic), banks with a higher degree of management diversity generally performed worse.

The study revealed, however, that a higher degree of management diversity before the Covid-19 pandemic had a positive or neutral effect on TCR levels while with the outbreak of the pandemic TCR increased regardless of the degree of bank management bodies diversity. Only the example of the German banking sector proves that a higher diversity of bank management boards guarantees a higher security of banks, regardless of the circumstances.

The analysis carried out and the results of the research do not unequivocally show that a higher degree of diversity in banks' management bodies is a reliable way of solving the problems of increasing the efficiency of banks' activities and their security at the same time. Even the introduction of penalties for banks with insufficiently diverse management bodies by banking supervision will not eliminate the risky behavior of individuals whose actions are determined by the structure of their central nervous system.

The solution to this problem could be neurobanking, which, as a sub-discipline of banking, would deal with the impact of the structure and functioning of the human central nervous system on the security of the individual bank and the banking system as a whole. The implementation of the concept of neurobanking would make it possible to ensure that all bank managers would provide a guarantee of due performance of their operations.

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Appendix

Table 2.

The final list of banks

Poland		France		Germany	
1.	Alior Bank S.A.	1.	Banque Palatine	1.	Aareal Bank AG
2.	Bank BPH S.A.	2.	BNP Paribas Group	2.	Bank für Sozialwirtschaft AG
3.	Bank Handlowy w Warszawie S.A.	3.	BPCE	3.	BHW Bausparkasse AG
4.	Bank Millennium S.A.	4.	CIC Banque Transatlantique	4.	Commerzbank AG
5.	Bank Ochrony Środowiska S.A.	5.	Credit Agricole	5.	Deutsche Bank AG
6.	Bank Pocztowy S.A.	6.	Credit du Nord	6.	Deutsche Pfandbriefbank AG
7.	Bank Polska Kasa Opieki S.A.	7.	Dexia Credit Local	7.	DKB Deutsche Kreditbank AG
8.	Bank Polskiej Spółdzielczości S.A.	8.	Groupe Credit Mutuel	8.	Hamburg Commercial Bank AG
9.	BNP Paribas Bank Polska S.A.	9.	HSBC France	9.	HSBC Trinkaus &Burkhardt AG
10.	Credit Agricole Bank Polska S.A.	10.	La Banque Postale	10.	IKB Deutsche Industriebank AG
11.	Deutsche Bank Polska S.A.	11.	PSA Banque France Group	11.	Oldenburgische Landesbank AG
12.	DnB Bank Polska S.A.	12.	RCI Banque SA	12.	Santander Consumer Bank AG
13.	Getin Noble Bank S.A.	13.	Societe Generale	13.	Teambank AG
14.	ING Bank Śląski S.A.			14.	UBS Europe S.E.
15.	mBank Hipoteczny S.A.			15.	UniCredit AG
16.	mBank S.A.			16.	Wüstenrot Bausparkasse AG
17.	Nest Bank S.A.				
18.	Pekao Bank Hipoteczny S.A.				
19.	PKO Bank Hipoteczny S.A.				
20.	Plus Bank S.A.				
21.	Powszechna Kasa Oszczędności Bank Polski S.A.				
22.	Santander Bank Polska S.A.				
23.	Santander Consumer Bank S.A.				
24.	SGB-Bank S.A.				
25.	Toyota Bank Polska S.A.				

Source: Own elaboration.

INDUSTRY 4.0 APPLICATIONS BASED ON THE BUSINESS MODEL CANVAS

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Purpose: The aim of the article is to indicate in which areas of the Business Model Canvas (BMC) companies use Industry 4.0 technologies and which Industry 4.0 technologies are most frequently used in BMC.

Design/methodology/approach: The study uses a mixed-methods approach, combining a systematic literature review with a quantitative survey to analyze the application of Industry 4.0 technologies across the nine areas of the Business Model Canvas. A matrix framework integrating selected technologies with BMC elements enables both literature analysis and empirical validation based on survey data from enterprises.

Findings: The research revealed that the technologies most widely used in BMC include Big Data & Artificial Intelligence, Cloud Computing, Internet of Things, and Industry Internet of Things. In turn, the areas with the greatest application of Industry 4.0 technologies at BMC are: value proposition, key activities, and key resources.

Research limitations/implications: In the case of survey research, the limitation is the sample size from specific geographic areas. Other significant limitations include the level of awareness of digital transformation in organizations, which will change over time.

Practical implications: From a research perspective, the study's findings will enable other researchers to continue their research to better understand the applications of Industry 4.0 technologies in selected BMC areas or industry sectors. In turn, entrepreneurs will be able to implement specific Industry 4.0 technologies in selected BMC areas.

Social implications: Entrepreneurs may prioritize implementing Industry 4.0 technologies such as Big Data & Artificial Intelligence, Cloud Computing, Internet of Things, and Industry Internet of Things. They can also begin implementing these technologies in areas of the business model such as the value proposition, core activities, and key resources.

Originality/value: Unlike other previous studies, this provides insight into the application of Industry 4.0 technologies in each of the nine BMC areas.

Keywords: Business Model Canvas, Industry 4.0, survey research.

Category of the paper: Research paper.

1. Introduction

Industry 4.0 is a paradigm that encompasses the convergence of digital and physical technologies, which is expected to bring greater efficiency to manufacturing and service companies. The term and concept known as “Industry 4.0” was proposed in 2011 by a German federal government initiative involving universities and private companies, and was later popularized during the Hannover Messe trade fair in 2011 (Kagermann, Lukas, Wahlster, 2011) (Ortt, Stolwijk, Punter, 2020). But what is "Industry 4.0"? Currently, there are many similar definitions. For the purposes of this article, the following definition was adopted: "Industry 4.0 is an idea, vision, concept based on a paradigm in which the process of integrating resources at the digital and physical level takes place in order to create intelligent organizations characterized by a high degree of production efficiency". Specific technologies attributed to Industry 4.0 are important in this process, such as: data integration systems, autonomous robots and cobots, drones, AGV technologies, digital Twins, cyber-physical systems, the Internet of Things, sensors, cybersecurity, cloud computing and analysis using artificial intelligence and machine learning algorithms, 3D printing, communication technologies such as RFID or 5G, augmented and virtual reality (Jamwal, Agrawal, Sharma, Giallanza, 2021). The complexity of the processes related to the transformation towards Industry 4.0 forces companies to adopt appropriate implementation strategies, tailored to the type of business or project characteristics (Müller, Buliga, Voigt, 2018; Śledziewska, 2025). Questions arise: which technologies should be implemented to achieve the intended effects? In which areas of the business model should they be applied? The business model, in particular, is a crucial issue. Research has shown that companies struggle to generate profits from new technologies without implementing appropriate business models (Abdelkafi et al., 2013). Considering the level of saturation with modern technologies, technologies within the Industry 4.0 concept, this problem will intensify among many enterprises taking up the challenge based on digital transformation towards Industry 4.0.

2. Framework & research questions

Transformation towards Industry 4.0 in an enterprise can proceed discreetly (stepwise), taking into account the enterprise's current technological infrastructure in the process of collecting, analyzing, and using data (e.g., through sensorization, introducing selected Industry 4.0 technologies into production), but also in a way that allows the enterprise to radically modernize towards Industry 4.0. The degree of technological change will largely depend on the enterprise's investment capabilities and the goals it intends to achieve through the

implementation of new technologies. The issue of applying Industry 4.0 technologies in an enterprise arises. This raises questions: in which areas of operations should the enterprise apply Industry 4.0 technologies? Which of these technologies should be applied in a given area of the enterprise? To answer these questions, a simple yet universal framework is needed.

This framework reflects the business activities of enterprises across various industries and sectors, while also allowing for the placement of Industry 4.0 technologies within it. This requirement is met by the Business Model Canvas template, which consists of nine blocks. Five blocks: customer segment, value proposition, channels, customer relationships, and revenue streams represent the area directly related to the customer, while the blocks: key resources, key activities, key partners, and cost structure represent the back-end of business model implementation. All these blocks allow for the creation of not only a business model but also the analysis of various business models and strategies for the organization's needs. Each of these blocks can be analyzed as an area of potential application of Industry 4.0 technologies. This structure allows for easy identification of specific applications of Industry 4.0 technologies in a given element of the business model, e.g., the use of AI with robots to manage production processes or the use of Digital Twin technology to develop functionalities and features for new product value propositions. This creates the basis for the need for research, the results of which will provide answers to research questions such as:

RQ1: Can the existing research literature identify which Industry 4.0 technologies are most widely used in BMC?

RQ2: In which business model elements do the surveyed companies most frequently use Industry 4.0 technologies?

RQ3: Which Industry 4.0 technologies are most frequently used in BMC?

This leads to a specific research goal: identifying the areas of BMC in which companies use Industry 4.0 technologies. Obtaining answers to these questions will help determine future directions for implementing Industry 4.0 technologies in specific areas of the business model.

3. Research design

3.1. Research area

The research area focuses on the application of Industry 4.0 tools within specific areas of the Business Model Canvas (BMC) template (Osterwalder, Pigneur, 2010). The framework for the research area was therefore individual BMC areas, such as: customer segment, value proposition, channels, customer relationships, revenue sources, key resources, key activities, key partnerships, and cost structure. Each of the aforementioned blocks (elements) represented a specific area for the possible application of selected Industry 4.0 tools by enterprises.

The choice of the BMC template as the basic framework within the research area is justified by the tool's widespread recognition among many organizations, including most enterprises of all sizes. The selected set of Industry 4.0 technologies served as a basic selection list for the application of a specific technology in each of the nine elements of the template. This allowed for data collection and subsequent analysis for each of the nine BMC areas, as well as for a cross-sectional analysis of selected technologies across all BMC areas. Combining BMC with Industry 4.0 technologies allowed for the creation of a matrix within which the study could be conducted. Therefore, BMC templates and selected Industry 4.0 technologies constituted the foundation for the SLR-based study (Snyder, 2019) and the quantitative study based on a survey addressed to enterprises.

3.2. Research methods

Two research methods were used for this study. The first research method was a systematic literature review. The second research method was a quantitative survey-based study. (Creswell, Creswell, 2022; Fisher, 2017). A detailed description of the selected research methods is provided below.

The systematic literature review method aimed to first identify Industry 4.0 technologies used in specific research areas within the BMC template. The systematic literature review was conducted by developing keyword combinations, which were then used to conduct a search for articles through search engines in databases of scientific articles presenting applications of Industry 4.0 technologies in specific areas of the BMC template. Based on this, a database of articles was created. These articles were then further identified for their applications in BMC areas, enabling further selection based on the research objective and research questions. The research process was then continued using the developed matrix. This matrix consisted of the following fields: ordinal number, article authors, article title, year of publication, country of the lead author, publisher, number of citations, abstract, research methods, research hypotheses, research questions, research area, research objective, and nine BMC areas: value proposition, customer segments, customer relations, channels, key activities, key resources, key partners, sources of revenue, and cost structure. Each of these nine areas contained 15 Industry 4.0 technologies: AI - Artificial Intelligence Algorithms, CC - Cloud Computing, IoT - Internet of Things, IoTT - Industry Internet of Things, CS - Cybersecurity, CP - Cyber-physical, DT - Digital Twin, AM - Additive Manufacturing: 3D Printing, AR - Augmented Reality, BC - Block Chain, XG - 5G,6G, QC - Quantum Computing, EC - Edge Computing, MES - Manufacturing Execution System; RA - Robotics and Automation.

Table 1.

Analysis of Industry 4.0 technologies in selected articles: - no technology X-technology was mentioned in the article

Technologia	(Kagermann, Lukas; Wahlster, (2011))	(Sigov, Ratkin, Ivanov, Xu, Li. (2022))	(Tsaramirsis et al. (2022)); (Oks et al. (2022)),	(Oks et al. (2022))	(Jamwal et al. (2021))	(Logeswaran et al. (2024))	Rath, Khang (2024))	(Alqoud et al. (2022))	(Mithas et al. (2022))	(Ghobakhloo et al. (2022)).
AI	–	X	X	–	X	X	X	X	X	X
CC	–	X	X	X	X	X	X	X	X	X
IoT	X	X	X	X	X	X	X	X	X	X
IIoT	✓	X	X	X	X	X	X	X	X	X
Cs	–	X	X	X	X	X	X	X	X	X
Cp (CPS)	✓	X	X	X	X	X	X	X	X	X
DT	–	X	X	X	X	X	X	X	X	X
AM	–	X	X	–	X	X	–	X	X	X
AR	–	X	X	–	X	X	–	X	X	X
BC	–	X	X	–	X	X	–	X	X	X
XG (5G/6G)	–	X	X	–	X	X	X	X	X	X
QC	–	X	–	–	–	X	–	–	X	–
EC	–	X	X	X	X	X	X	X	X	X
MES	–	–	X	X	X	X	–	X	X	X
RA	–	X	X	X	X	X	–	X	X	X

Source: Authors own work.

The selection of Industry 4.0 technologies for the list is justified by scientific sources such as: Kagermann, Lukas, Wahlster, 2011; Sigov, Ratkin, Ivanov, Xu, 2022; Tsaramirsis et al., 2022; Oks et al., 2022; Jamwal et al., 2021; Logeswaran et al., 2024; Rath, Khang, 2024; Alqoud et al., 2022; Mithas, et al., 2022; Ghobakhloo et al., 2022). They constituted a canon for research purposes regarding the applied Industry 4.0 technologies. These articles list and describe Industry 4.0 technologies. The table 1 shows which of the articles indicates a given technology. Together, the above-mentioned articles allowed the creation of a complete, fully consistent, and ordered list of Industry 4.0 technologies. However, it is worth emphasizing that over time, new technologies of significant importance may appear and will be included in the Industry 4.0 set, therefore the developed list is functional in nature. It is not a normative list. This list is not intended to be theoretically exhaustive of the entire Industry 4.0 ecosystem. The list we constructed contributes to the analytical matrix as part of our systematic literature review. We treat the developed list as an operational reference set that forms the analytical matrix. Based on this matrix, information was gathered on the applications of specific Industry 4.0 technologies in each area of the BMC template. The collected data were used to develop statistics on the application of specific Industry 4.0 technologies in each area of the BMC template. The collected results enabled the identification of research methods, hypotheses, and research questions, thus identifying research gaps, as well as opportunities for developing new directions for future research, new research questions, and hypotheses. The results also had a practical impact, indicating which Industry 4.0 technologies may be key in their application in specific areas of the business model. The figure 1 below illustrates the subsequent stages of the method based on a systematic literature review.

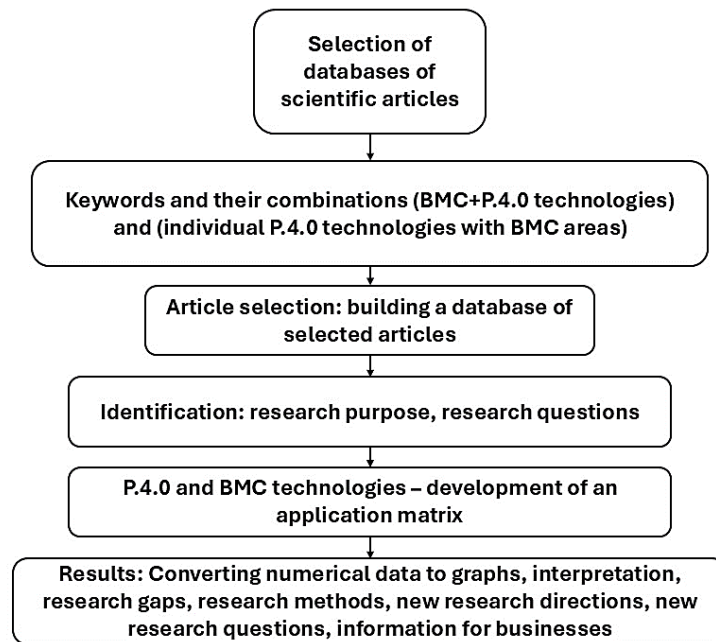


Figure 1. Schematic diagram of the systematic literature review conducted.

Source: Authors own work.

During the literature analysis, we used the following exclusion criteria:

1. The publication was outside the timeframe of the 2021-2025 study.
2. The document is not classified as an article or book chapter.
3. No explicit reference to Industry 4.0.
4. No explicit reference to one of the Industry 4.0 technologies.
5. Publications not directly related to the application of Industry 4.0 technologies in business, e.g., focusing on applications in government administration.

During the literature analysis, we used the following inclusion criteria:

1. Peer-reviewed scientific or industry publication.
2. The publication must explicitly use the term Industry 4.0 or explicitly refer to the Industry 4.0 architecture (RAMI 4.0).
3. The publication must mention at least one Industry 4.0 technology.
4. The publication must mention business applications that relate to BMC areas.
5. The publication must indicate the research methods used. As part of the research methods, a quantitative research approach was applied, based on a specially developed questionnaire. This research method was chosen due to its ability to empirically examine the use of 'Industry 4.0' technologies by enterprises within the individual areas of the BMC template. The quantitative, survey-based method enables the collection of data that reflects reality. The collected data makes it possible to obtain concrete, factual cognitive results not only through quantitative analysis and visualization in the form of charts, but also through the use of descriptive statistics. The questionnaire included multiple-choice questions (allowing the selection of several options). The multiple-

choice format makes it easy to construct questions regarding the application of Industry 4.0 technologies in each of the nine areas of the BMC template.

The following questions were developed:

1. Does your organization use Industry 4.0 technologies for customer segmentation? Please, indicate the technologies that are used in your organization (you can indicate more than one). If not, check the box "are not used".
2. Does your organization use Industry 4.0 technologies to create value proposition for customers? Please, indicate the technologies that are used in your organization (you can indicate more than one). If not, check the box "are not used".
3. Does your organization use Industry 4.0 technologies to optimize distribution channels? Please, indicate the technologies that are used in your organization (you can indicate more than one). If not, check the box "are not used".
4. Does your organization use Industry 4.0 technologies to build relationship with customers? Please, indicate the technologies that are used in your organization (you can indicate more than one). If not, check the box "are not used".
5. Does your organization use Industry 4.0 technologies to manage key activities? Please, indicate the technologies that are used in your organization (you can indicate more than one). If not, check the box "are not used".
6. Does your organization use Industry 4.0 technologies to collaborate with key partners? Please, indicate the technologies that are used in your organization (you can indicate more than one). If not, check the box "are not used".
7. Does your organization use Industry 4.0 technologies to optimize the revenue structure? Please, indicate the technologies that are used in your organization (you can indicate more than one). If not, check the box "are not used".
8. Does your organization use Industry 4.0 technologies to optimize the revenue structure? Please, indicate the technologies that are used in your organization (you can indicate more than one). If not, check the box "are not used".
9. Does your organization use Industry 4.0 technologies to optimize the cost structure? Please, indicate the technologies that are used in your organization (you can indicate more than one). If not, check the box "are not used".

The figure 2 illustrating the steps involved in conducting a quantitative study.

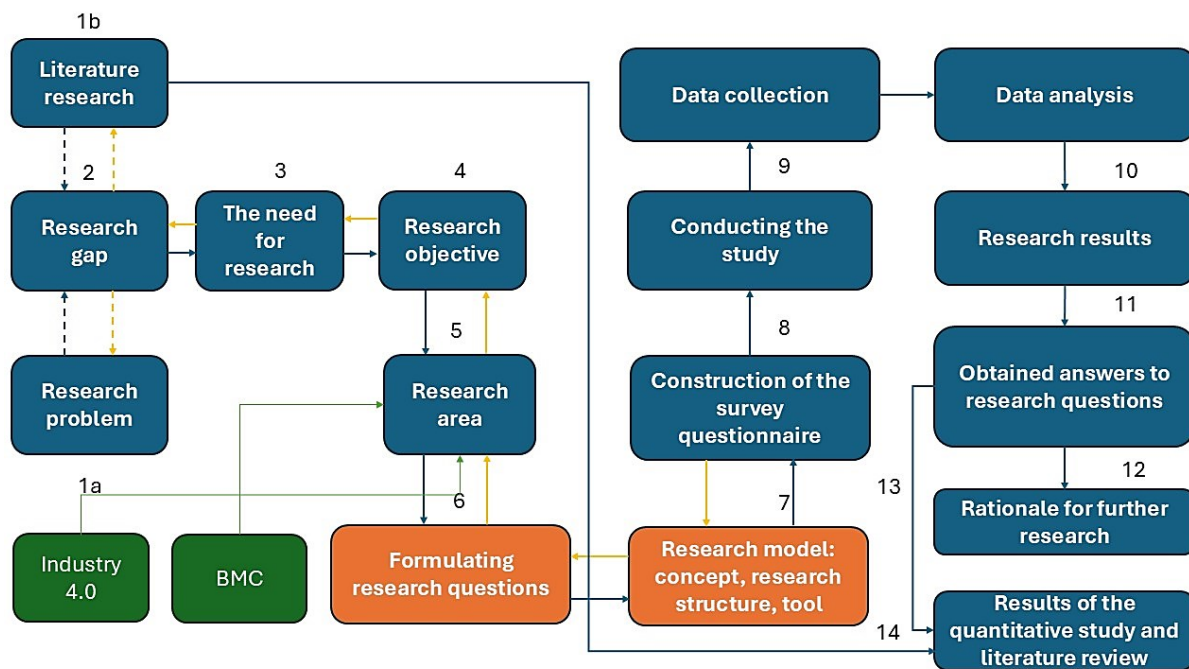


Figure 2. Diagram showing the steps involved in conducting a quantitative study.

Source: Authors own work.

The research sample was acquired during the international DEICy 2024 Digital Economy, Internet of Things, Cybersecurity (DEICy, 2024) event, which took place from November 25-29, 2024. A total of 405 entities, including enterprises, research institutes, universities, associations, and foundations, participated in the registration process. After data verification and cleaning, 359 valid records were qualified for further analysis, while 46 entries were rejected because they did not represent enterprises.

The structure of the study sample in terms of enterprise size was as follows:

- Microenterprises (1-9 employees) – 111 entities (31%),
- Small enterprises (10-49 employees) – 113 entities (32%),
- Medium-sized enterprises (50-249 employees) – 65 entities (18%),
- Large enterprises (250 or more employees) – 70 entities (19%).

In total, small and medium-sized enterprises (SMEs) constituted 81% of the study sample, while large enterprises constituted 19%.

The final research sample included only enterprises, in line with the research objectives and questions. They included:

- 211 commercial companies,
- 49 start-ups,

which together accounted for 72.5% of all registered event participants.

European companies accounted for the largest share, approximately 74%. Of these, 65% were from the EU and 9% were from Europe but outside the EU. Companies from the Middle East accounted for approximately 20%, followed by approximately 5% from East Asia.

4. Results

4.1. Literature research results

In accordance with the adopted research structure, a systematic literature review was first conducted. Based on the research objectives and research questions, 150 publications were identified and subjected to in-depth analysis using keyword combinations. The developed matrix allowed for the study, which yielded results regarding the applications of Industry 4.0 technologies within specific areas of the Business Model Canvas. Significant information regarding the application of research methods was also obtained, which allowed for the identification of gaps and new directions in research regarding the application of Industry 4.0 technologies in BMC. A detailed list of sources is presented in the References section [2-32][34-35][37-46][48-70][72-95][98-105][108-113][115-140][142-145][147-167].

First, an analysis of the research methods used was conducted. The chart below presents the percentage of individual research methods used in the area of Industry 4.0 applications.

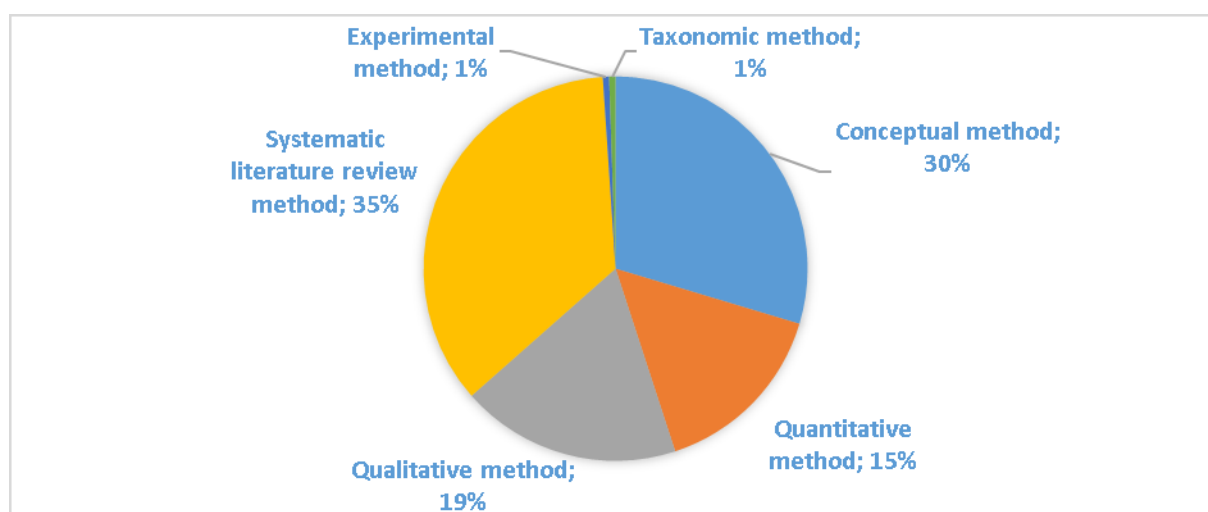


Figure 3. Percentage of research methods used on the application of Industry 4.0 technologies in BMC areas.

Source: Authors own work.

The study results (figure 3) indicate that the most frequently used research method is the systematic literature review method, with a 35% share. The conceptual method was next, with a 30% share. The qualitative method accounted for 19%. The quantitative method was next, with a 15% share. The remaining methods were the experimental research method and the taxonomic research method, both accounting for 1% of the total.

The next section of the analysis examined the number of Industry 4.0 technologies used in each area of the BMC framework. The table below presents the number of Industry 4.0 technologies used in each area of the BMC framework.

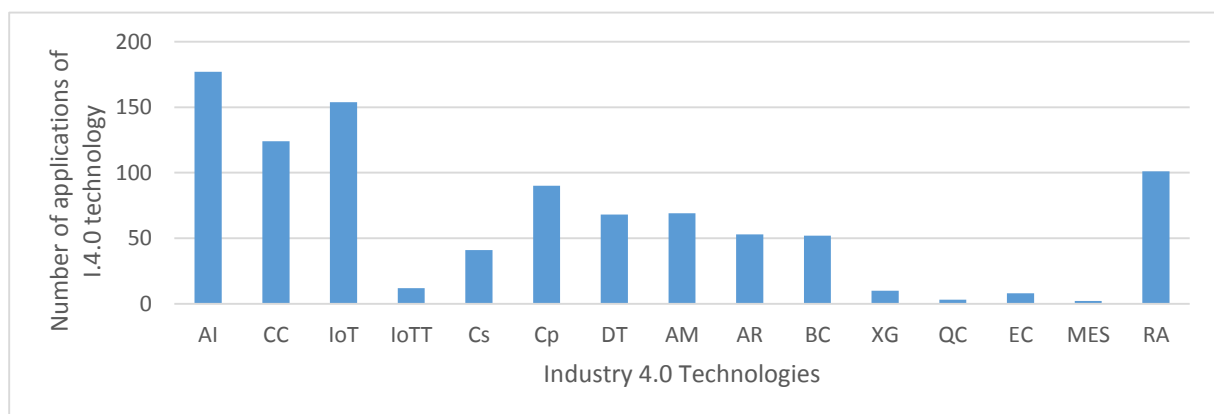
Table 2.*Industry 4.0 technologies used in individual BMC areas*

	VP	CS	CR	Ch	KA	KR	KP	RE	Co
AI	21	19	21	13	39	36	9	7	12
CC	18	5	9	10	33	32	8	4	5
IoT	19	12	11	12	35	37	7	8	13
IoT	2	1	0	2	2	1	2	0	2
Cs	7	1	4	2	9	11	1	2	4
Cp	9	2	4	5	27	25	5	4	9
DT	12	3	4	6	16	13	4	2	8
AM	10	1	2	4	21	17	3	3	8
AR	7	3	6	3	13	14	3	0	4
BC	8	4	5	8	10	10	4	1	2
XG	1	1	1	1	3	3	0	0	0
QC	0	0	0	0	1	2	0	0	0
EC	1	1	1	1	2	2	0	0	0
MES	0	0	0	0	1	1	0	0	0
RA	11	2	6	6	27	28	5	5	11

Source: Authors own work.

The study results (table 2) indicate that solutions based on AI algorithms are among the most prominent Industry 4.0 technologies. Their application is particularly evident in areas such as: value proposition (21), customer relationships (21), key activities (39), and key resources (36). The next technology is CC computer cloud, which has the greatest applications in areas such as: value proposition (18), key activities (33), and key resources (32). The next technology is IoT, which has the greatest applications in areas such as: value proposition (19), key activities (35), and key resources (37). Considering IIoT technologies, the following values apply: value proposition (21), key activities (37), and key resources (38). Another prominent technology is RA robotics and automation, which has the greatest applications in areas such as key activities (27) and key resources (28). Another technology is Cyber-Physical, so-called cyber-physical technologies, the greatest applications of which are in the area of key activities (27) and key resources (25). Among other technologies, it is worth paying attention to the use of Additive Manufacturing AM technologies in the area of key activities (21) and key resources (17) and Digital Twin in the area of key activities (16) and key resources (13).

Research results also indicate which technologies have the most applications.

**Figure 4.** Application of specific Industry 4.0 technologies at BMC – SLR.

Source: Authors own work.

The figure shows that technologies such as Artificial Intelligence, Cloud Computing, IoT & IIoT stand out among Industry 4.0 technologies.

A summary analysis of the application of Industry 4.0 technologies at BMC was also conducted. The results are presented in the figure 5.

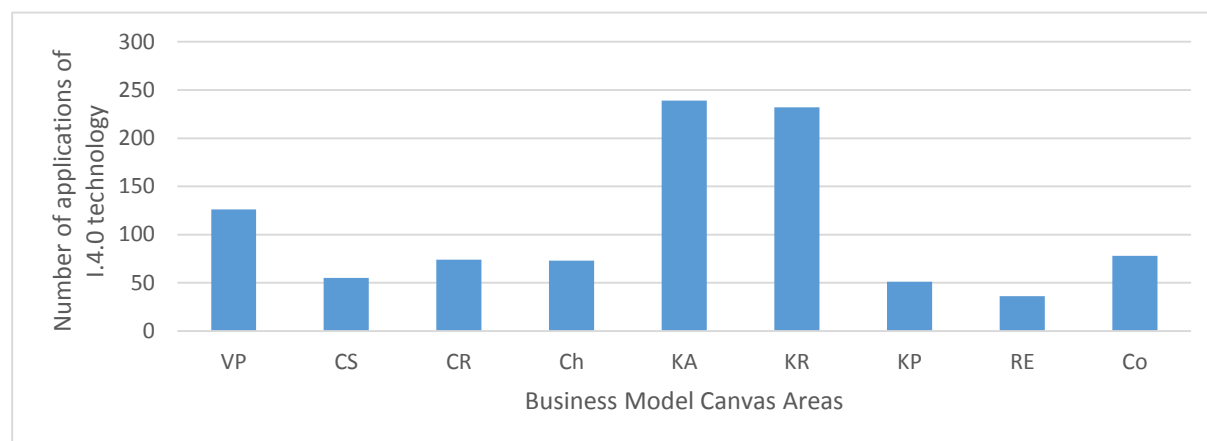


Figure 5. Application of BMC areas with Industry 4.0 technologies – SLR.

Source: Authors own work.

The study results indicate that the greatest application of Industry 4.0 technologies is in areas such as core activities (239) and key resources (232). Significant application is also noted in value propositions (126).

4.2. Survey Results

Data collected as part of the survey was first cleaned and filtered to detect irregularities, but also to ensure accuracy and consistency. Data was obtained through responses to questions during registration for brokerage meetings and the DEICy 2024 "Digital Economy, Internet of Things, Cybersecurity" (DEICy, 2024) workshops. During registration, survey participants responded to questions by indicating the application of Industry 4.0 technologies. The prepared data allowed for subsequent conversion into graphical charts and the estimation of basic statistical measures. This process resulted in two summary charts. The first chart shows the application of Industry 4.0 technologies in BMC, and the second chart shows the application of Industry 4.0 technologies in a given BMC area. These summary charts were supplemented with selected static measures, such as mean, standard deviation, and coefficient of variation. The results for the individual BMC areas are presented below.

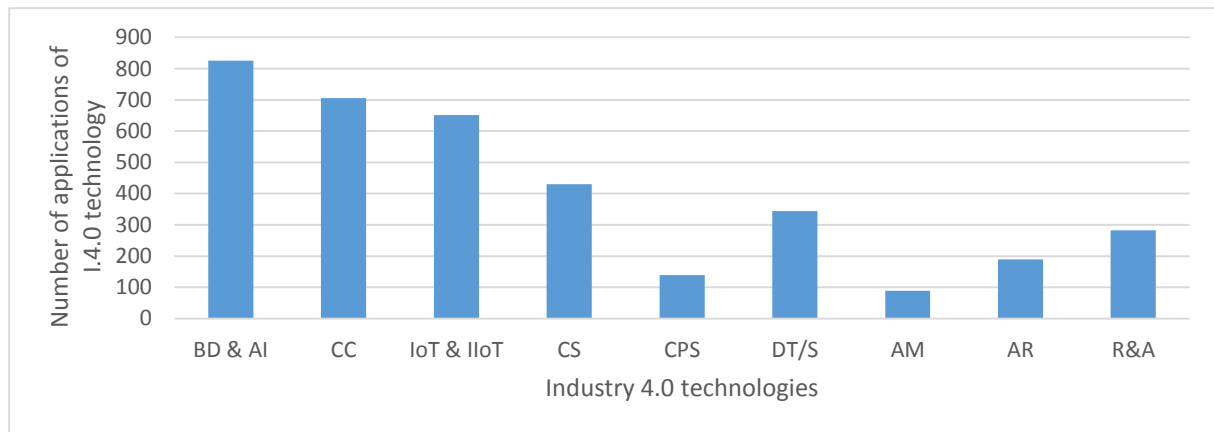


Figure 6. Applications of individual P.4.0 technologies in BMC.

Source: Authors own work.

Based on the conducted research, a figure 6 of applications of individual Industry 4.0 technologies within the BMC template concept was created. The results indicate that solutions based on BD & AI (826) are among the most prominent Industry 4.0 technologies. Cloud Computing (706) is next in terms of applications. This is closely followed by the Internet of Things (IoT) and Industrial Internet of Things (IIoT) (651). Cybersecurity (CS) (430), followed by Digital Twin/Simulation (DT/S) (344). Robotics and Automation (R&A) (283) is also prominent (189). Cyber-Physical Systems (CPS) (139) and Additive Manufacturing (AM) (89) are also prominent.

Additionally, calculations of basic statistical metrics were performed. The table below presents the values of selected metrics.

Table 3.

Selected statistical measures of the applications of individual Industry 4.0 technologies

Name of technology	Mean	Standard deviation	Coefficient of variation	Median
Big Data and Artificial Intelligence analytics	91,78	8,70	9,48%	90,00
Cloud computing	78,44	7,91	10,08%	81,00
Internet of Things or Industry Internet of Things	72,33	12,25	16,93%	71,00
Cybersecurity	47,78	6,16	12,89%	47,00
Cyber-Physical Systems (CPS)	15,44	2,30	14,87%	15,00
Digital Twin/Simulation	38,22	6,72	17,59%	39,00
Additive Manufacturing (3D Printing)	9,89	1,76	17,84%	10,00
Augmented Reality	21,00	4,64	22,08%	21,00
Robotics and Automation	31,44	7,43	23,64%	32,00

Source: Authors own work.

The table 3 shows that "Algorithms" play a greater role than "Hardware". The data in the table clearly demonstrates that digital transformation primarily occurs in the realm of algorithms and data (BD, AI, Cloud), and only then in the realm of physical machines (Robotics, 3D Printing). This approach makes it easier and cheaper to purchase access to cloud analytics than to install a robotic line. The data in the table also demonstrates the high adoption of IoT and IIoT. This demonstrates that companies are willing to invest in implementing sensors, actuators, digital meters, industrial routers, and network infrastructure, e.g., WiFi, 5G,

and combining it with existing fixed assets (even analog ones), rather than investing in new fixed assets. If companies are willing to purchase a new fixed asset, e.g., a robot, it is a "spot" purchase to improve the process at a given point in the production process. Purchasing a new robotic production line is rare. On the other hand, for IoT and IIoT, the median (71,00) is close to the mean (72,33), but the large data dispersion (deviation 12,25) and significant coefficient of variation (16,93) suggest that the market is quite polarized in this regard. This polarization is a warning sign. The gap between leaders and the rest of the companies in the IoT space will continue to widen. Companies that have not yet invested in collecting data from machines may soon lose the opportunity to implement AI. They simply will not have anything to power their algorithms. It seems that a scenario based on the "trinity" of BD&AI, Cloud Computing, IoT, and IIoT is the starting point for accelerating the transformation towards Industry 4.0 in industrial enterprises.

Another interesting comparison involved creating a chart that shows the application of all Industry 4.0 technologies in a specific area of the BMC template. This type of chart provides an overview of the saturation of a given BMC area with Industry 4.0 technologies. The results indicate that the value proposition (519) is among the areas with the highest saturation with Industry 4.0 technologies. Customer segmentation (428) is the second most important area. Next are two areas with the same results: key activities (420) and key partners (420). Key resources (402) and customer relationships (400) are next. Distribution channels (381) are next. Cost structure (350). The summary concludes with the revenue structure, with a score of (337). These results are presented in the figure 7.

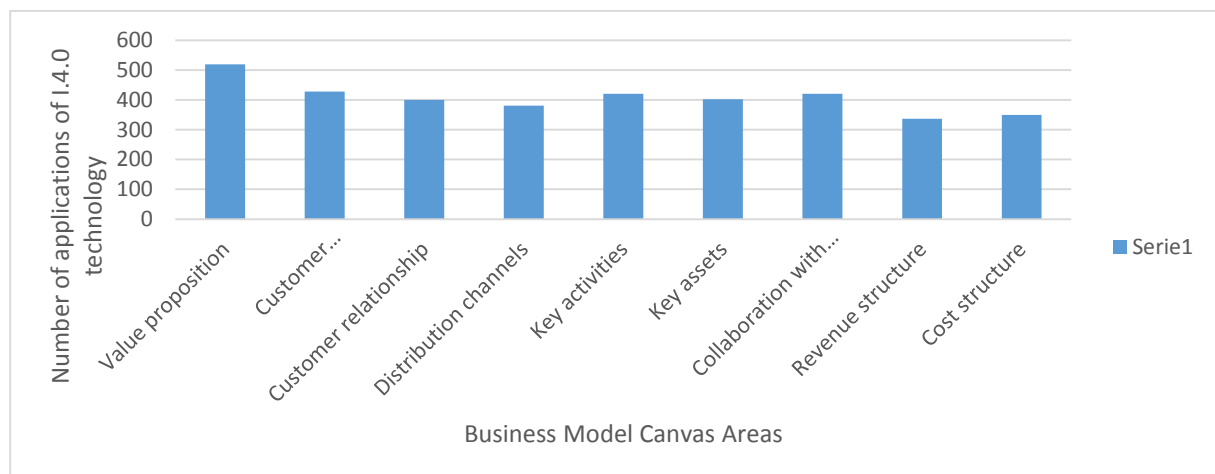


Figure 7. Application of BMC areas with Industry 4.0 technologies.

Source: Authors own work.

Figure 7 shows that value propositions, customer segmentation, and key activities are areas that can be prioritized by enterprises as part of digital transformation based on Industry 4.0 technologies. Additionally, calculations of basic statistical metrics were performed. The table 3 below presents the values of selected metrics.

Table 4.*Selected statistical metrics of Industry 4.0 technology saturation in specific BMC areas*

Name of technology	Mean	Standard deviation	Coefficient of variation	Median
Value proposition	57,67	35,34	61,29%	52
Customer segmentation	47,56	29,45	61,93%	41
Customer relationship	44,44	30,17	67,89%	41
Distribution channels	42,33	26,02	61,46%	39
Key activities	46,67	31,90	68,35%	39
Key assets	44,67	30,21	67,64%	35
Collaboration with partners	46,67	30,27	64,87%	37
Revenue structure	37,44	26,93	71,91%	28
Cost structure	38,89	26,78	68,87%	32

Source: Authors own work.

Table 4 shows that Value Propositions is the area most saturated with Industry 4.0 technologies. Companies are leveraging AI, Big Data, and other Industry 4.0 technologies to modernize their products and services, offering increasingly advanced functionalities, features, and personalization. In general, firms are seeking to increase competitiveness through innovation. It is worth noting, however, that the median (52) is lower than the mean, suggesting that a small group of highly advanced companies significantly inflates the overall result, while the typical company has reached only about half of the possible level of maturity. Therefore, it is important to consider the role of Industry 4.0 technologies and how they translate into innovation not only at the organizational level but also in terms of products and services. The market segmentation results indicate a shift from traditional segmentation approaches toward data-driven segmentation based on Big Data. This transition is still in progress. A mean below 50 suggests that most companies have not progressed beyond the data collection stage; although they are already able to perform Big Data analyses, they are not yet capable of automatically adapting their offerings in real time. This indicates that a broader use of AI-based tools may be necessary. It is also worth highlighting the area of key actions. The low median (39) indicates that a significant number of surveyed companies have not yet transitioned beyond “Industry 3.0.” They may be investing in modern machinery; however, two major problems remain. First, operational processes are not yet saturated with intelligent technologies, which suggests that technology is still treated mainly as a support tool rather than a driving force of transformation. Second, there is a lack of organizational readiness for change. Much more effort is needed to build awareness of digital transformation—understood not as overlaying new technologies onto old processes, but as a fundamental redesign of processes based on intelligent technologies—and to manage change effectively. If this awareness does not evolve, a paradox may emerge in which, as a civilization, we continue to develop AI technologies but attempt to fit them into outdated industrial or business structures. Therefore, further research is needed on the organization and management of Industry 4.0 technologies.

Discussion

From the perspective of the conducted research—a systematic literature review and a quantitative study—the obtained results enabled us to answer the research questions RQ1: Can the existing research literature identify which Industry 4.0 technologies are most widely used in BMC? RQ2: In which business model elements do the surveyed companies most frequently use Industry 4.0 technologies? RQ3: Which Industry 4.0 technologies are most widely used in BMC? For the first question, RQ1, the research results using a systematic literature review indicate that these technologies include AI, IoT & IIoT, Cloud Computing, and also robotization and automation. From the perspective of the research results, a quantitative method based on the RQ3 survey revealed that the most widely used Industry 4.0 technologies in BMC are BD&AI, Cloud Computing, IoT & IIoT, and also cybersecurity solutions. In terms of RQ2, based on the survey results, we can identify the value proposition, customer segmentation, key activities, key partners, and key processes. The results of the systematic literature review indicate that these include: key processes, key resources, and the value proposition.

As part of the discussion, we compare the results of our study with the findings of other research. First, we compare our results with the study by Julian Marius Muller, *Business model innovation in small and medium sized enterprises. Strategies for industry 4.0 providers and users* (Müller, 2019). This article presents the results of a qualitative study aimed at examining the impact of Industry 4.0 on the business models of SMEs in the manufacturing sector. The study focused on the mechanical and machinery engineering industry, the automotive industry, and the electrical industry, as these sectors were considered the most affected by Industry 4.0. Interviews were conducted to explore changes in business models related to the adoption of Industry 4.0 technologies, with a total of 43 interviews carried out: 24 from mechanical and machinery engineering companies, 13 from automotive suppliers, and 6 from the electrical sector. The study showed that *Key Resources* were the most frequently mentioned business model component (58.14% of respondents), primarily focusing on two aspects: production facilities and equipment needing modification or purchase according to specifications, or adaptation of existing machinery, also known as “modernization”. This is a notable finding in terms of digital transformation toward Industry 4.0, as it involves applying digital solutions to analog assets. Importantly, there is alignment with our findings: in both our systematic literature review and survey-based quantitative study, Key Resources are among the areas with the highest concentration of Industry 4.0 technologies. The only difference is their ranking: in the literature review, Key Resources are second, while in the survey they are third. The *Value Proposition* is the second most frequently mentioned component (53.49% of respondents), focusing on new products, services, or combinations thereof offered to customers. Our findings confirm that Value Proposition is among the areas

with significant Industry 4.0 technology adoption, ranking third in the literature review and first in the quantitative survey. *Key Partners* were the third most cited component in Muller's study (48.84% of respondents), while in our survey-based study, it ranks fourth, showing a somewhat similar trend. Interestingly, Muller's study indicates that *Key Activities* were the second least frequently mentioned component (23.26% of respondents), whereas in our research, Key Activities played a significant role in the application of Industry 4.0 technologies, ranking first in the literature review and fifth in the survey, suggesting this area requires further investigation.

Next, we compared our results with those of Giuditta Pezzotta, Veronica Arioli, Federico Adrodegari, et al., in the article *The Digital Servitization of Manufacturing Sector: Evidence from a Worldwide Digital Servitization Survey* (Pezzotta et al., 2023). This study targeted managers of SMEs in the manufacturing sector, with main objectives including: (1) analyzing how manufacturing firms implement digital technologies to support the shift from a product-based business model to a service-oriented one, and (2) identifying key challenges and best practices characterizing digital transformation in manufacturing companies. Relevant to our study were the findings on the current state of Industry 4.0 technology implementation in service delivery. The authors reported the following adoption rates: IoT (50%), Cloud Computing (47%), Cybersecurity (43%), Big Data Analytics (35%), Simulation & Connected Machines (24%), AR (23%), AI/ML (20%), Advanced Manufacturing Solutions (13%), Additive Manufacturing (13%). They also identified the potential for further adoption: IoT (33%), Cloud Computing (32%), Cybersecurity (30%), Big Data Analytics (43%), Simulation & Connected Machines (43%), AR (42%), AI/ML (49%), Advanced Manufacturing Solutions (31%), Additive Manufacturing (27%). The authors note that small enterprises (26% of the sample) lag in implementing digital/intelligent technologies, mainly investing in the three most widely used technologies (IoT, Cloud Computing, Cybersecurity), while large enterprises (47%) are increasingly adopting more complex digital/intelligent technologies. Comparing these findings with our survey-based results, there is alignment in the adoption of Cloud Computing, IoT & IIoT, Cybersecurity, and BM & AI technologies (combined in our study), corresponding to Pezzotta et al.'s results prior to potential increase in Big Data Analytics (35%) and AI/ML (49%), with a total of 84%, the highest among all technologies. After this adjustment, the overall picture of Industry 4.0 technology adoption aligns with our survey results.

Other notable findings from our survey-based quantitative study include the variability of Industry 4.0 technology applications across different business model areas. Variability indices indicate heterogeneous adoption, which may result from diverse business models and corresponding technology needs. Alternatively, low digital awareness or maturity regarding Industry 4.0 applications in specific business models may limit practical implementation. These insights provide a basis for developing new hypotheses and conducting further research.

It is worth emphasizing the differences between the literature and the empirical research. The article shows that SLR clearly points to the areas of Key Activities, Key Resources, and Value Proposition as the dominant areas for Industry 4.0 technology applications. The survey, in turn, points to Value Proposition, Customer Segmentation, and Key Activities. Therefore, there is a clear agreement regarding areas such as Key Activities and Value Proposition. There is a noticeable difference between Key Resources and Customer Segmentation. The literature research indicates greater applications in the back-office, while the survey research points to the so-called front-office, i.e., Customer Segmentation. On the one hand, these differences may stem from different perspectives – the literature research focuses on conceptual applications, while enterprises implement technologies according to current needs and investment opportunities. It should be noted that conceptual research accounts for 30% of the research methods. A tempting prospect regarding key resources is the ability to adapt existing assets in conjunction with Industry 4.0 technologies, for example, within IoT and IIoT. Installing sensors to control analog devices allows for optimal use and translates into lower energy costs.

It's also worth noting that the customer groups or recipients to whom a company targets its products or services significantly impact financial results, for example, the Return on Sale (ROS) indicator. Applying Industry 4.0 technologies, particularly Big Data and Artificial Intelligence analytics, to activities such as market segmentation can contribute to better offer tailoring and price optimization, leading to increased sales and, consequently, better financial results.

The results of both the SLR and survey studies also raise the question: "Why are some technologies more prevalent in business models than others?" On the one hand, the use of technologies such as BD & AI, Cloud Computing, and IoT/IIoT is clearly noticeable, while on the other hand, the implementation of Quantum Computing and MES is low. Important factors may include business needs, the degree of implementation, process adaptability, universality, the organization's maturity to implement technology, company size, cost vs. revenue. Business needs may indicate the viability of implementing technologies that will translate into results in a given business model. Ease of implementation will contribute to the rapid implementation of technology into business processes, adaptability allows for the technology to be applied to various types of problems within a given category, and universality may indicate applications in various business areas. The organization's maturity to technology, such as acceptance vs. resistance to technological change, is also important. Company size may indicate that a large enterprise has a greater chance of using, for example, MES (Manufacturing Execution System) technology, which promotes vertical and horizontal integration and is even an essential tool for more efficient company operation. In a small or medium-sized enterprise, CRM (Customer Relationship Management), MRP (Material Requirements Planning), or ERP (Enterprise Resource Planning) may play a more important role. In turn, technology such as quantum computing can be used where very large data sets, complex simulations, or advanced research

and development projects are involved. It seems that such technology may primarily find applications in large organizations.

From the perspective of researching topics related to the application of Industry 4.0 technologies in specific BMC areas, the study results indicate a unique opportunity to create various configurations for different business models. These primarily include configurations between selected Industry 4.0 technologies. These can also include configurations in which Industry 4.0 technologies are combined with older technologies often referred to as analog. For example, the sensorization of analog devices (which have analog meters and indicators) for beverage production allows not only for digital measurement but also for data collection and analysis to optimize processes. It is clear, however, that the study results do not demonstrate the possible configuration paths for these technologies for different types of companies. However, they do indicate which areas are worth starting with specific technologies. On the one hand, at the deductive level, the study met its assumptions regarding the general results, but on the detailed level, further research is undoubtedly needed. The results of this study should be considered a map of the applications of Industry 4.0 technologies in specific BMC areas. These results can contribute to further research into specific configurations of technology implementation paths for different types of enterprises, for example, at the level of conceptual research or case study research. We believe that the research findings can also provide a reference point for Industry 4.0 technology configurators to develop proprietary technology configurations for their clients.

Conclusion

This article presents the results of two studies. The first was conducted using a systematic literature review, and the second was conducted using a quantitative survey. The results provided answers to the research questions RQ1: Can the existing research literature identify which Industry 4.0 technologies are most widely used in BMC? RQ2: In which business model elements do the surveyed companies most frequently use Industry 4.0 technologies? RQ3: Which Industry 4.0 technologies are most widely used in BMC? The research revealed that BD&AI, Cloud Computing, and IoT & IIoT are among the technologies most widely used in BMC. The areas with the highest application of Industry 4.0 technologies in BMC are: value proposition, key activities, and key resources, according to the systematic literature review and survey.

From the perspective of researching topics related to the application of Industry 4.0 technologies in specific BMC areas, the study results indicate a unique opportunity to create various configurations for different business models. These primarily include configurations between selected Industry 4.0 technologies. These can also include configurations in which

Industry 4.0 technologies are combined with older technologies often referred to as analog. For example, the sensorization of analog devices (which have analog meters and indicators) for beverage production allows not only for digital measurement but also for data collection and analysis to optimize processes. It is clear, however, that the study results do not demonstrate the possible configuration paths for these technologies for different types of companies. However, they do indicate which areas are worth starting with specific technologies. On the one hand, at the deductive level, the study met its assumptions regarding the general results, but on the detailed level, further research is undoubtedly needed. The results of this study should be considered a map of the applications of Industry 4.0 technologies in specific BMC areas. These results can contribute to further research into specific configurations of technology implementation paths for different types of enterprises, for example, at the level of conceptual research or case study research. We believe that the research findings can also provide a reference point for Industry 4.0 technology configurators to develop proprietary technology configurations for their clients.

Quantitative survey research revealed high coefficients of variation regarding the application of Industry 4.0 technologies in specific areas. Based on these results, we proposed developing research hypotheses that this state of affairs is influenced by the diversity of research business models or that it results from a low level of awareness and maturity regarding the application of Industry 4.0 technologies in specific business models, e.g., within a given industry. These hypotheses should be examined by a wider group of researchers.

The study also had limitations. In the case of the literature review, the research framework we developed focused on the use of single research methods. During data analysis, it was observed that two or even three methods were being used simultaneously to study the application of Industry 4.0 technologies in different areas of the BMC template. Another limitation of the literature study was its limited number. It is impossible to rule out the possibility that the review (search engine algorithms) did not identify publications that could be included in the literature review database. Another significant limitation was the size of the literature review database. In the case of survey studies, the natural limitation is the research sample. Other significant limitations include the level of awareness of digital transformation within organizations, which may also affect the completeness of the picture of Industry 4.0 applications in BMC within enterprises.

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THE JANUARY EFFECT AND FIRM SIZE: EVIDENCE FROM THE WARSAW STOCK EXCHANGE (2000-2024)

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Purpose: This paper examines the existence, differentiation, and evolution of the January effect on the Warsaw Stock Exchange over the period 2000-2024, with particular emphasis on differences between large-cap and small-cap market segments and on changes associated with market maturation.

Design/methodology/approach: The study analyses monthly logarithmic returns of the WIG20 and sWIG80 indices using descriptive statistics, data visualisation, and inferential testing. Seasonality is assessed with one-way ANOVA and the Kruskal-Wallis test, complemented by sub-period analysis for 2000-2008 and 2009-2024. The theoretical framework draws on the Efficient Market Hypothesis and the literature on calendar anomalies and firm size effects.

Findings: No statistically significant monthly seasonality is identified for either index over the full sample period, indicating the absence of a persistent January effect at the aggregate market level. Nevertheless, descriptive results show relatively higher January returns in the small-cap segment. Sub-period analysis reveals a weakening of January returns after 2008, suggesting a declining economic relevance of the anomaly as the market matures.

Research limitations/implications: The analysis is based on monthly index data and does not account for transaction costs or taxation. Future research could employ firm-level or higher-frequency data and incorporate behavioural or institutional factors.

Practical implications: The findings indicate that the January effect has limited applicability as an investment strategy on the contemporary Polish stock market, particularly after accounting for risk and market efficiency.

Originality/value: The paper provides a long-horizon, segment-based analysis of the January effect on the Warsaw Stock Exchange, highlighting its gradual weakening and structural transformation in a post-transition market.

Keywords: January effect; calendar anomalies; stock market seasonality; market efficiency; Warsaw Stock Exchange.

Category of the paper: research paper.

1. Introduction

The presence of calendar anomalies has long posed a challenge to the Efficient Market Hypothesis (EMH), according to which financial asset prices fully reflect all available information. Under this assumption, earning abnormal returns based on historical data should not be possible (Malkiel, 2003). One of the most extensively documented deviations from this premise is the January effect (Patel, 2016). This phenomenon refers to the observation that stock returns in January, particularly for small-cap firms, are significantly higher than in other months of the year (Cooper, McConnell, Ovtchinnikov, 2006).

The empirical foundations of research on the January effect were laid by Rozeff and Kinney (1976), who demonstrated, using evidence from the U.S. market, that average January returns substantially exceeded those recorded in other months. Subsequent studies, including those by Roll (1983), Gultekin and Gultekin (1983), and Thaler (1987), further refined the understanding of this anomaly by highlighting its strong association with firm size. The literature most frequently identifies tax-related motives and window dressing practices employed by investment funds as the primary mechanisms underlying the January effect (Haug, Hirschey, 2005). At the same time, more recent research increasingly emphasizes a weakening of this anomaly. The tendency toward a gradual decline in the January effect became particularly evident after the global financial crisis of 2008 (Darrat, Li, Chung, 2013).

The January effect has also been the subject of numerous studies conducted on the Polish capital market. Domestic researchers have employed a variety of methods to measure abnormal returns and have adopted different econometric approaches. Grotowski (2008), using, *inter alia*, GARCH-type models, identified the presence of the January effect on the Warsaw Stock Exchange (WSE), while simultaneously emphasizing its limited economic significance. In turn, Szczepańska-Przekota (2024), applying the CENSUS X12 procedure, linked the periodic disappearance of this anomaly to changes in the structure of investors. The conclusions drawn from these studies, as well as from the work of Pawlonka and Sypniewski (2023), are consistent with findings in the international literature, indicating that on the WSE the January effect primarily concerns smaller firms and exhibits varying intensity over time.

At the same time, existing studies on the WSE have generally focused on shorter time horizons or selected market segments, which hampers a clear assessment of the persistence of the January effect under conditions of a maturing capital market. In particular, there is a lack of analyses covering a long, coherent observation period and enabling a direct comparison of the behavior of different groups of firms. This article addresses this research gap by focusing on a comparative analysis of two key segments of the Warsaw Stock Exchange over the period 2000-2024. The study examines the largest companies included in the WIG20 index as well as small-cap firms represented by the sWIG80 index. The main objective of the paper is to verify the presence of the January effect on the WSE over a long, 25-year time horizon, with particular

emphasis on its differentiation by firm size. The research problem concerns an assessment of the current relevance of this anomaly in the context of a contemporary capital market and an examination of whether, in line with the classical literature, the January effect in Poland primarily pertains to low-capitalization firms.

2. Literature review

2.1. Calendar Anomalies and the January Effect

The Efficient Market Hypothesis (EMH), formulated by Fama (1970), provides a fundamental reference point for the analysis of market anomalies. According to its assumptions, stock prices should fully reflect all available information, implying that investment strategies based on historical price patterns are ineffective. As empirical research developed, however, recurrent deviations from this framework began to be identified. Thaler (1987) referred to such regularities as market anomalies, among which the January effect occupies a prominent position in the literature.

Although systematic research on calendar anomalies began in the 1970s, early observations pointing to atypical market behavior at the beginning of the year appeared much earlier. Wachtel (1942) drew attention to seasonality in stock returns on the U.S. market, while Officer (1975) identified similar patterns on the Australian stock exchange. The importance of Officer's study lies in its analysis of a market operating under a different tax cycle, with the fiscal year ending in June, which later enabled researchers to test the tax-loss hypothesis independently of the calendar year-end.

A significant stage in the development of research on the January effect was the study by Rozeff and Kinney (1976), who were among the first to apply econometric tools to the analysis of data from the New York Stock Exchange (NYSE) covering the period 1904-1974. They demonstrated that average stock returns in January were markedly higher than in other months of the year, which stimulated further investigations across different markets. Subsequent research by Gultekin and Gultekin (1983) confirmed the presence of the January effect not only in the United States but also across most developed-country markets.

For the purposes of the present study, particularly relevant is the strand of literature focusing on the relationship between calendar anomalies and firm size. Banz (1981) identified the so-called small-firm effect, showing that companies with lower market capitalization tend to achieve higher average returns. Keim (1983) subsequently demonstrated that a substantial portion of this premium is concentrated in January. Roll (1983) concluded that the January effect is closely linked to the firm size effect, a relationship that can be regarded as constitutive for further considerations of the economic mechanisms underlying this anomaly.

2.2. Mechanisms of the January Effect

The literature proposes several approaches to explain the mechanisms underlying the January effect. Most commonly, three groups of explanations are distinguished: the tax-loss selling hypothesis, institutional practices referred to as window dressing, and factors related to market microstructure.

The most widely cited explanation remains the tax-loss selling hypothesis, independently formulated by Branch (1977) and Dyl (1977). According to this approach, investors sell loss-making assets toward the end of the tax year in order to reduce their tax liabilities. The resulting selling pressure in December leads to a temporary undervaluation of stock prices, while their repurchase in January generates renewed demand and, consequently, higher returns. More recent studies, however, suggest that the economic relevance of this mechanism may be limited, particularly in emerging markets. Caporale and Zakirova (2017), analyzing the Russian market, showed that the January effect appears primarily as a statistical regularity rather than as the basis for a profitable investment strategy. Although January exhibited higher returns in raw data, the anomaly largely disappeared once transaction costs were taken into account.

A second group of explanations focuses on institutional mechanisms, particularly the practice of window dressing employed by investment funds. Lakonishok, Shleifer, Thaler, and Vishny (1991) argued that portfolio managers may adjust asset holdings at the end of the year in order to present portfolios with a lower perceived risk profile in annual reports. Such actions can generate seasonal shifts in demand for specific asset classes. More recent evidence, however, calls into question the universality of this explanation. Kaul et al. (2025) demonstrated that the January effect was already present in the United States during the period 1874-1917, when neither income taxation nor institutionalized investment funds existed. They documented that average January returns exceeded those in other months by approximately 3.1%, suggesting that neither tax optimization nor formal institutional arrangements constitute a necessary condition for the emergence of this anomaly.

Complementing the fiscal and institutional perspectives is the behavioral approach. Ciccone (2011) argues that the January effect may be linked to psychological factors influencing investor decision-making. The beginning of a new calendar year functions in financial markets as a symbolic “new start,” fostering increased optimism and a greater willingness to take risk. This phenomenon is associated with the so-called false hope syndrome, defined as an unjustified belief in improved future investment performance (Ciccone, 2011, p. 159). Elevated investor sentiment in January may translate into higher demand for assets characterized by greater uncertainty, contributing to short-term price increases and, in a longer horizon, potentially leading to overvaluation and subsequent performance deterioration.

The mechanisms outlined in the literature provide the interpretative framework for the empirical analyses conducted in this study.

2.3. The specificity of the January Effect in emerging markets: the case of the Warsaw Stock Exchange

The analysis of the January effect in the context of emerging markets constitutes an important complement to findings derived from studies of developed markets. Poland, as a market positioned between these two categories, provides an interesting setting for examining the persistence of the January effect under conditions of progressing institutionalization and increasing market efficiency. Lewandowska (2017) notes that anomalies in the distribution of stock returns, including the January effect, were observed on the Warsaw Stock Exchange (WSE) even prior to the introduction of the capital gains tax in 2004. This observation challenges the tax-loss selling hypothesis in the Polish context, suggesting that tax optimization was not the primary source of this phenomenon. At the same time, more recent studies emphasize the evolution of the January effect and its pronounced segmentation. Borowski (2019), analyzing a sample of 91 companies listed on the WSE, demonstrated that the January effect occurs more frequently among firms with low and medium market capitalization. These findings are consistent with the strand of literature linking calendar anomalies to the small-firm effect. Similar conclusions in an international setting were presented by Szymański and Wojtalik (2020), who showed that the main stock indices in Poland, the Czech Republic, and Hungary have gradually exhibited characteristics of more efficient markets, while indices composed of smaller firms continue to generate excess returns at the beginning of the year.

At the same time, some authors question the current relevance of the January effect on the WSE. Keller (2016), analyzing the WIG20, mWIG40, and WIG250 indices over the period 2000-2013, found no statistically significant evidence of this anomaly and interpreted the results as an indication of market maturation. A similar position is taken by Myśliwiec (2020), who, based on data from 2015-2020, considered the results to be inconclusive and questioned the significance of January as a month generating above-average returns. A different perspective was proposed by Lewandowska (2017), who drew attention to the presence of a so-called December effect, which in certain phases of a bull market may outweigh January gains.

Index-based analyses are complemented by sectoral and cross-market studies. Lisicki (2018) demonstrated that the January effect on the WSE is heterogeneous and varies across industries. Borowski (2018), in turn, indicated that this form of seasonality is more pronounced in the equity market than in commodity markets. An alternative perspective was offered by Pieloch-Babiarz (2020), who linked the occurrence of seasonality to dividend payment cycles.

The most recent studies also take into account the impact of extraordinary events and macroeconomic shocks. Lisicki (2025), analyzing the behavior of the WSE during the COVID-19 pandemic and the post-pandemic period, showed that heightened volatility driven by macroeconomic factors can distort or weaken traditional calendar patterns, thereby limiting the usefulness of simple historical analogies in crisis periods.

In summary, the literature suggests that the January effect is strongly dependent on firm size and the stage of market development, which justifies conducting a comparative analysis of the WIG20 and sWIG80 indices over a long-term horizon.

3. Research method

3.1. Research objectives and hypotheses

The primary objective of the study is to assess the presence and differentiation of the January effect on the Warsaw Stock Exchange (WSE) over a long-term horizon, with particular emphasis on differences between market segments representing firms with varying levels of market capitalization. The analysis aims to determine whether the calendar regularities documented in the literature persist under conditions of a maturing capital market.

Based on prior empirical and theoretical studies on calendar anomalies, firm size effects, and the time-varying nature of the January effect, particularly those documenting its concentration among small-capitalization stocks and its weakening in mature markets, the following research hypotheses are formulated:

- H1: Stock returns of companies listed on the WSE exhibit seasonal variation across individual months of the year, with January displaying behavior that differs from that observed in other months.
- H2: The magnitude and statistical significance of the January effect vary with firm size, with the phenomenon being relatively more pronounced in the small-cap segment (sWIG80) than in the large-cap segment (WIG20).
- H3: The relevance of the January effect on the WSE weakens over time, a trend that is particularly evident in the segment of the largest companies.

3.2. Data sources and sample construction

The empirical analysis is based on historical price data for the main stock market indices of the Warsaw Stock Exchange (WSE), namely WIG20 and sWIG80, obtained from the financial data service Stooq.pl. The study focuses on the seasonality of stock market returns, with particular attention paid to differences between market segments representing firms with varying levels of market capitalization.

All statistical computations and data visualizations were conducted using the R programming environment (RStudio). The research sample covers the period from January 2000 to December 2024, which enables an examination of the January effect over a long-term horizon and an assessment of its evolution across successive stages of market development.

The data preparation stage involved standardizing date formats and reducing the dimensionality of the dataset by retaining only observations containing the date and monthly closing prices of the indices. Subsequently, the data were transformed by computing logarithmic returns and constructing auxiliary variables, including calendar year, month, and a grouping variable used to assign observations to predefined subperiods.

To capture potential changes in the nature of the January effect over time, two analytical subperiods were distinguished. The first subperiod covers the years 2000-2008 and corresponds to the phase of dynamic development of an emerging market, Poland's accession to the European Union, and the period preceding the global financial crisis. The second subperiod spans the years 2009-2024 and reflects a stage of market stabilization and structural maturation, as well as deeper integration of the WSE into the global financial system.

3.3. Variables and statistical analysis methods

The primary measure used in the analysis was the logarithmic monthly rate of return of the stock market indices, calculated according to the following formula:

$$R_t = \ln \frac{P_t}{P_{t-1}} \quad (1)$$

where:

R_t – rate of return in month (t),

P_t – index closing price in month (t),

P_{t-1} – index closing price in the preceding month.

The use of logarithmic returns is a standard approach in financial market research and improves the statistical properties of the analyzed time series, particularly with respect to data aggregation and the interpretation of percentage changes (1).

For each calendar month, basic descriptive statistics were computed, including the arithmetic mean, median, standard deviation, and sample size. The distributions of monthly returns were examined visually using bar charts and boxplots, which allowed for the identification of outliers and the assessment of distributional asymmetry.

The hypothesis testing procedure was conducted in a stepwise manner. In the first step, the assumption of homogeneity of variances across monthly returns was examined using Bartlett's test. Subsequently, the normality of empirical distributions was assessed using the Shapiro-Wilk test. The results indicated violations of the normality assumption, which justified a cautious approach to the application of parametric methods.

Despite these limitations, a one-way analysis of variance (ANOVA) was performed in the next stage to provide a parametric assessment of differences among mean monthly returns. In parallel, the non-parametric Kruskal-Wallis test was applied. Due to its robustness to outliers and the absence of a normality requirement, the Kruskal-Wallis test was treated as the decisive procedure in the verification of the research hypotheses.

Hypothesis H1, concerning seasonal variation in stock returns across calendar months, was tested by comparing the distributions of monthly returns using both one-way ANOVA and the Kruskal-Wallis test. Hypothesis H2, which addresses differences in the strength of the January effect depending on firm capitalization, was verified by comparing January returns for the WIG20 and sWIG80 indices, with analyses conducted separately for each market segment. The verification of Hypothesis H3, which assumes a weakening of the January effect over time, was based on subperiod analysis and a comparison of statistical test results across the identified phases of market development.

In all statistical tests, the significance level was set at $\alpha = 0.05$.

4. Results and discussion

4.1. Seasonality of monthly returns on the WSE

In the first stage of the analysis, the suitability of one-way analysis of variance (ANOVA) for examining the seasonality of monthly returns of the WIG20 and sWIG80 indices was assessed. For this purpose, the fundamental assumptions of parametric testing were verified, including the homogeneity of variances and the normality of residual distributions.

For the WIG20 index, Bartlett's test did not provide grounds for rejecting the hypothesis of equal variances across calendar months ($K^2 = 17.807$; $p = 0.086$). At the same time, the Shapiro–Wilk test conducted on the model residuals indicated a statistically significant deviation from normality ($W = 0.98814$; $p = 0.015$). The results of the one-way ANOVA confirmed the absence of a statistically significant effect of the “month” variable on the returns of the WIG20 index ($p = 0.343$).

In the case of the sWIG80 index, violations of the parametric test assumptions were more pronounced. Bartlett's test confirmed significant heterogeneity of variances in monthly returns ($p = 0.034$), indicating that return volatility differs across calendar months. The Shapiro–Wilk test also revealed a lack of normality in the residual distribution ($p < 0.001$; specifically, 3.004×10^{-5}). Under these conditions, the result of the classical ANOVA ($p = 0.233$) was deemed unreliable.

Given the violation of the normality assumption for both indices and the lack of variance homogeneity in the case of sWIG80, further analysis of monthly return seasonality was based on the non-parametric Kruskal-Wallis test.

The results of this test for the WIG20 index did not indicate a statistically significant effect of the calendar month on the level of returns ($H = 14.031$; $df = 11$; $p = 0.2312$). This suggests that no significant monthly seasonality was observed in the segment of the largest companies listed on the Warsaw Stock Exchange during the analyzed period. Analogous results were

obtained for the sWIG80 index, for which the test statistic equaled $H = 13.149$ and the p-value was 0.2837. This indicates the absence of statistically significant differences between monthly returns also in the segment of small-cap companies.

4.2. Analysis of the January Effect in Subperiods

To assess the robustness of the results and to verify whether the lack of statistical significance over the entire sample period may be driven by the averaging of opposing tendencies, an additional seasonality analysis was conducted for two subperiods: 2000-2008 and 2009-2024.

For the WIG20 index, the Kruskal-Wallis test did not reveal statistically significant differences between monthly returns in either of the analyzed subperiods. In the years 2000-2008, the p-value amounted to 0.9026, while in the period 2009-2024 it equaled 0.3514. These results confirm the absence of monthly seasonality in the segment of the largest companies both before the global financial crisis and in the subsequent period.

Similarly, no statistically significant differences between calendar months were identified for the sWIG80 index in either subperiod. In the years 2000-2008, the p-value reached 0.8869. It should be noted, however, that the average January return in this period was relatively high, amounting to 4.49%. At the same time, the high volatility of monthly returns meant that the observed difference did not reach statistical significance. In the second subperiod (2009-2024), the p-value equaled 0.3929, which confirms a further weakening of seasonal effects in the small-cap segment.

4.3. Characteristics of monthly returns over the entire sample period

The inferential analysis conducted using the Kruskal-Wallis test is complemented by a descriptive examination of monthly returns based on data visualizations for the entire sample period 2000-2024. This analysis makes it possible to assess whether the lack of statistical significance identified in the nonparametric tests is reflected in the structure of mean values and in the distribution of observations.

The charts of average monthly returns (Figure 1 and Figure 2) reveal noticeable differences between the analyzed indices. In the case of the sWIG80 index, January stands out as the month with the highest average return, amounting to 3.6%. Relatively high values are also observed in February (2.1%) and April (2.4%). Such a pattern may suggest the presence of a positive seasonal effect at the beginning of the year in the small-cap segment.

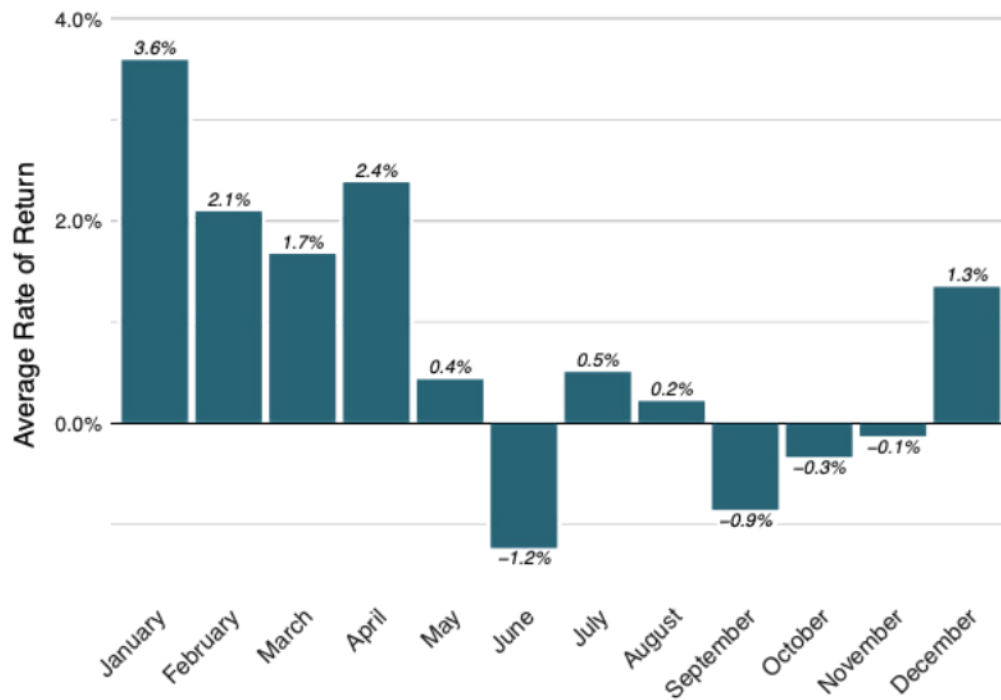


Figure 1. Average Monthly Rates of Return sWIG80.

Source: Own elaboration.

A different situation is observed for the WIG20 index, where January does not constitute a dominant month and its average return amounts to only 0.3%. The distribution of average monthly returns for this index is more irregular, with a particularly pronounced negative anomaly occurring in September, characterized by an average loss of -2.8%.

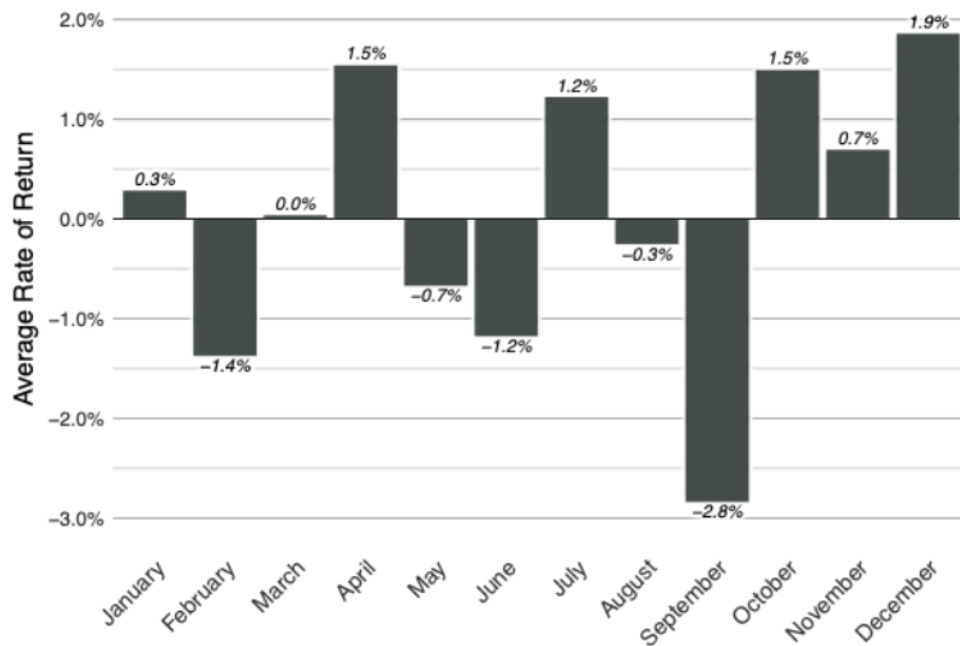


Figure 2. Average Monthly Rates of Return WIG20.

Source: Own elaboration.

An explanation for the lack of statistical significance of the monthly effect is provided by box plots illustrating the distribution of monthly returns (Figure 3 and Figure 4).

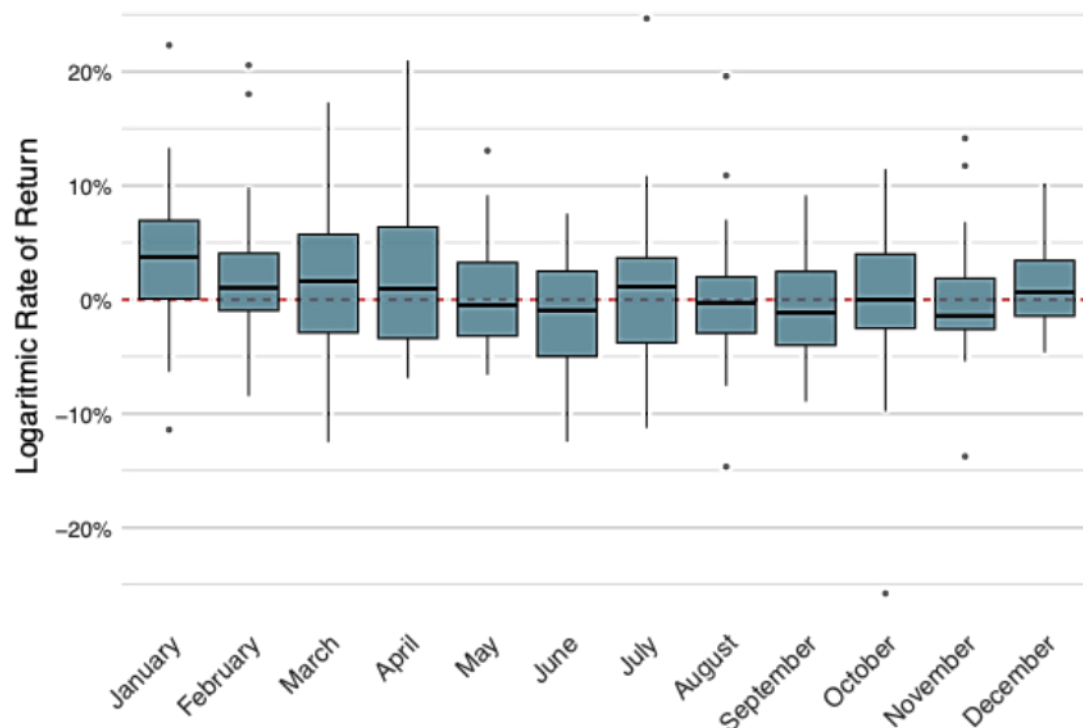


Figure 3. Distribution of sWIG80 Returns.

Source: Own elaboration.

For the sWIG80 index, despite the relatively high average return in January, a substantial interquartile range and numerous outliers can be observed. The high volatility of observations across individual months significantly affects the stability of mean values and limits the ability to identify a systematic seasonal effect at the statistical level.

A corresponding analysis for the WIG20 index does not provide evidence supporting the existence of a regular January anomaly. January is characterized by a wide range of return fluctuations, and the distribution of observations does not show a concentration of positive values. High volatility and the presence of extreme observations undermine the stability of any potential positive seasonal effects, which remains consistent with the results of the nonparametric tests.

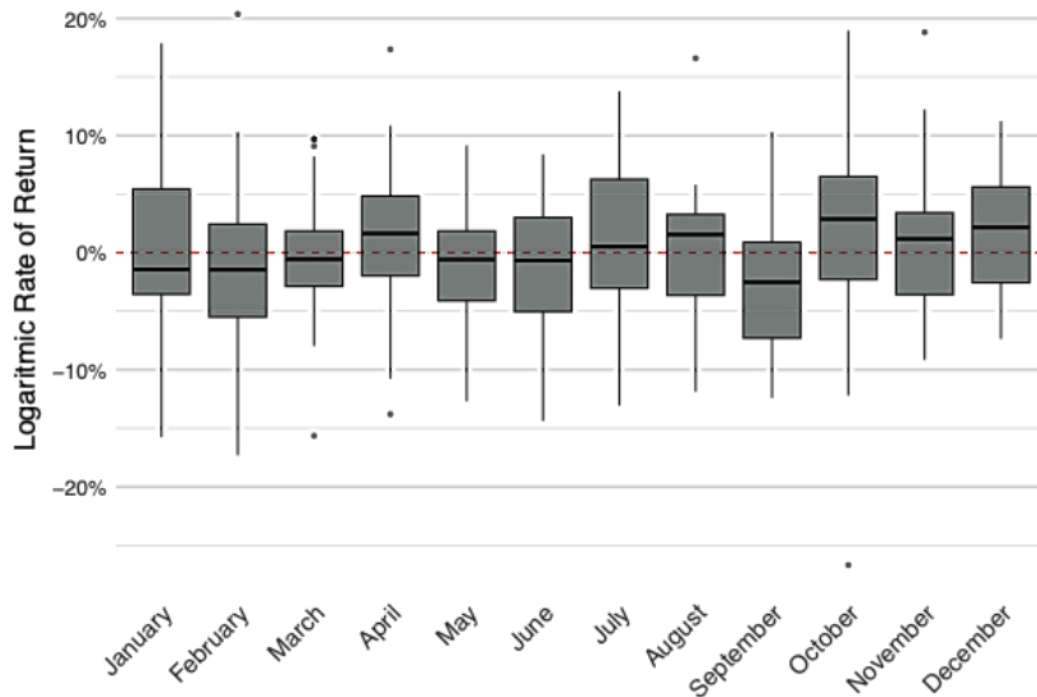


Figure 4. Distribution of WIG20 Returns.

Source: Own elaboration.

4.4. Evolution of the January Effect in the subperiods 2000-2008 and 2009-2024

The objective of this part of the analysis was to assess whether the strength of the January effect changed as the capital market matured. To this end, average monthly returns were compared for the pre-crisis period (2000-2008) and for the years 2009-2024.

Figure 5 presents a comparison of average monthly returns for the sWIG80 index across both subperiods. A weakening of returns in the early months of the year is clearly observable. In the years 2000-2008, the average returns in January and February amounted to 4.6% and 4.5%, respectively, whereas in the period 2009-2024 they declined to 3.1% and 0.7%. This indicates a reduction in the magnitude of seasonal excess returns in the small-cap segment.

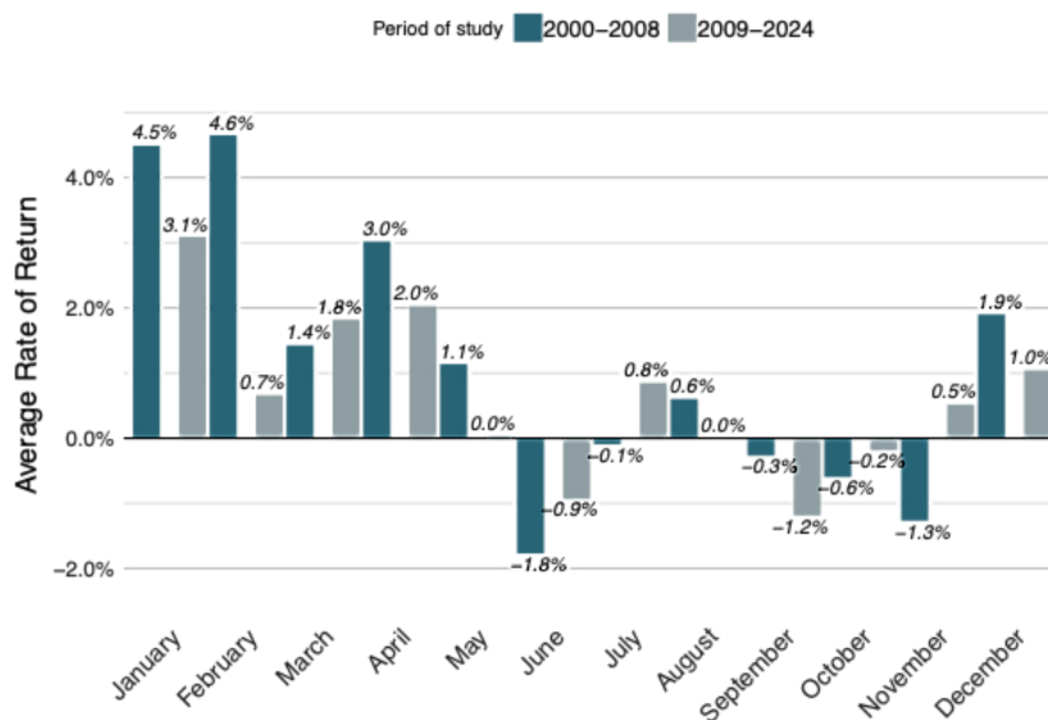


Figure 5. Comparison of Average Rates of Return sWIG80.

Source: Own elaboration.

An analogous comparison for the WIG20 index is shown in Figure 6. In both subperiods, September remains a month characterized by negative average returns; however, in the years 2009-2024 the scale of declines is markedly smaller than in the pre-crisis period.

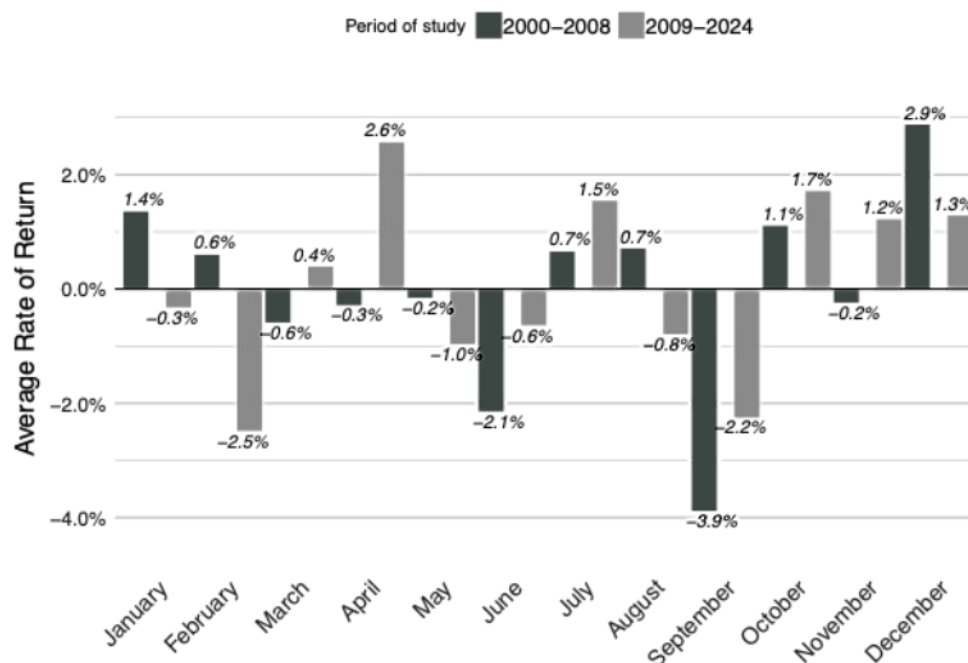


Figure 6. Comparison of Average Rates of Return WIG20.

Source: Own elaboration.

4.5. Structural changes in return volatility

Complementing the analysis of average values, the distributions of monthly returns in both subperiods were compared using box plots. This approach allows for an assessment of changes in volatility and in the structure of risk.

Figures 7 and 8 illustrate clear differences between the period 2000-2008 and the years 2009-2024. In the latter subperiod, a narrowing of the interquartile range and a shortening of the whiskers can be observed, indicating a decline in the volatility of monthly returns.

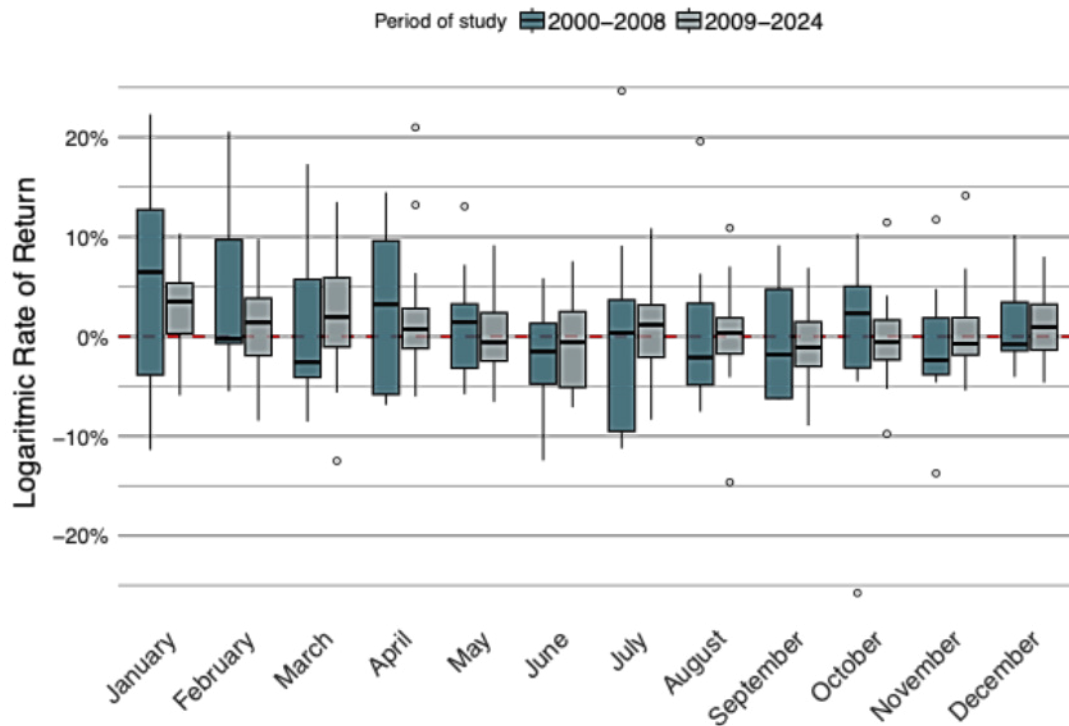


Figure 7. Diminishing Volatility: Comparison of sWIG80 Rates of Return.

Source: Own elaboration.

This pattern is evident in both the small-cap and large-cap segments, suggesting increased market stability in the later stage of its development.

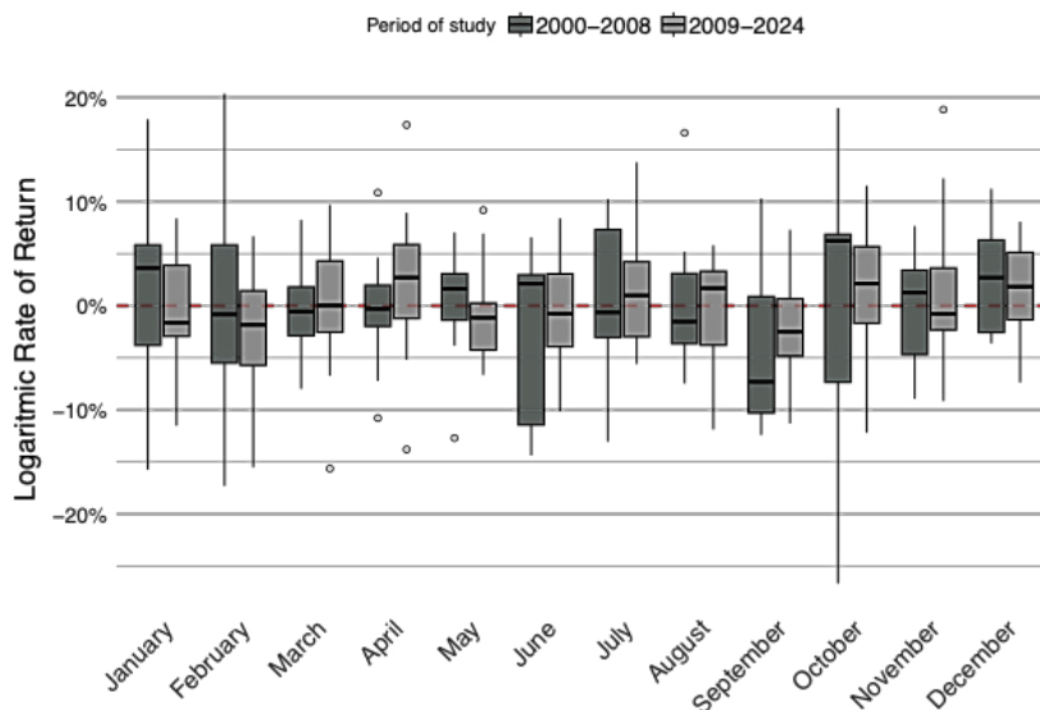


Figure 8. Diminishing Volatility: Comparison of WIG20 Rates of Return.

Source: Own elaboration.

4.6. Discussion of the research results

The results of the statistical tests did not reveal statistically significant differences between monthly returns over the entire 25-year study period, which implies a lack of empirical support for confirming hypothesis H1 in its global formulation. In particular, January does not differ from other months in a statistically significant manner, as the p-values obtained for both analysed indices exceeded the adopted significance level. These findings are consistent with the assumptions of the Efficient Market Hypothesis and suggest that, under contemporary conditions of the Warsaw Stock Exchange, simple calendar anomalies do not generate systematic excess returns. This observation is consistent with recent international evidence provided by Enow (2024), who, upon revisiting the January anomaly in global stock markets, concluded that while the effect may have been prominent in the past, it is no longer evident in modern, efficient financial systems due to arbitrage activities.

At the same time, descriptive analysis and the visualisation of average monthly returns indicate a clear differentiation between market segments. In the small-cap segment, represented by the sWIG80 index, January was characterised by a relatively higher average return compared with the WIG20 index. Although this difference did not reach statistical significance over the full time horizon, its directional character remains consistent with hypothesis H2 and with earlier findings in the literature, which point to a concentration of seasonal anomalies among firms with lower capitalisation. This specific market behavior is corroborated by the recent findings of Pawlonka and Sypniewski (2023). Their research on the WSE confirms that the

January effect persists as a statistically significant phenomenon primarily in the segment of small and medium-sized companies, whereas it has largely disappeared from the main indices representing the largest capitalisation stocks.

The analysis of the subperiods provides additional insights into the evolution of the January effect on the Polish market. In the years 2000-2008, when the Warsaw market exhibited features typical of an emerging market, January was associated with relatively high average returns, particularly in the small-cap segment. Following the global financial crisis of 2008, a clear flattening of monthly returns was observed, accompanied by changes in their dispersion, which limited the ability to identify stable seasonal patterns. These results provide empirical support for hypothesis H3, which assumes a weakening of the January effect over time as the market matures, especially in the segment of the largest companies. Such temporal variability finds theoretical and empirical backing in the work of Kołatka (2020), who tested the Adaptive Market Hypothesis on the WIG index (1994-2019) and demonstrated that market efficiency is not constant but cyclical, explaining why anomalies may exist in earlier development stages and disappear as the market evolves.

In a synthetic perspective, the obtained results indicate that the lack of statistical significance of the January effect does not necessarily imply its complete disappearance, but rather a transition from a regular anomaly to a phenomenon that is unstable and strongly dependent on market structure and the stage of market development. This instability in the most recent years is further documented by Lisicki (2025), who showed that in the post-pandemic reality of the WSE, the January effect is no longer consistent and depends heavily on unexpected market events.

5. Conclusion

The aim of the study was to empirically verify the existence of the January effect on the Warsaw Stock Exchange, taking into account differences related to firm capitalisation and changes occurring over a long time horizon. The analysis of returns for the WIG20 and sWIG80 indices over the period 2000-2024 did not provide grounds for confirming hypothesis H1 in its global formulation, as no statistically significant differentiation of monthly returns was identified over the entire sample period.

At the same time, the results of the structural and descriptive analyses indicate directional differences between market segments. Relatively higher average January returns observed for the sWIG80 index, in the absence of analogous tendencies for the WIG20 index, provide partial support for hypothesis H2, which assumes a stronger manifestation of the January effect in the small-cap segment. It should be emphasised, however, that this advantage is nominal in nature

and did not receive confirmation at the level of statistical significance across the full research horizon.

An important contribution of this study to the existing literature is the demonstration of the time-varying nature of the analysed phenomenon. Dividing the 25-year period into subperiods made it possible to show that the relatively high January returns observed prior to 2008 weakened markedly in the post-crisis period. This result confirms hypothesis H3 and points to a process of maturation of the Warsaw capital market, which is increasingly resembling developed markets where seasonal anomalies are of limited importance or tend to disappear.

When interpreting the results, several limitations of the study should be taken into account. First, the analysis is based on aggregate index-level data, which does not allow for the identification of firm-level drivers of seasonal return patterns. Second, the use of non-parametric tests, while robust to deviations from normality, limits the ability to control for additional risk factors and dynamic effects. Third, the study does not incorporate transaction costs and tax burdens, which may substantially reduce the potential investment benefits implied by the observed regularities, especially in the small-cap segment.

In view of these limitations, future research could focus on analysing the behaviour of individual investors in order to identify possible behavioural or tax-related determinants of seasonal anomalies. Further studies could also extend the analysis to real (inflation-adjusted) returns and examine seasonal effects using higher-frequency data, for example at the level of selected trading days during the year, which may reveal short-term patterns not observable in monthly data. Additionally, comparative analyses including other Central and Eastern European capital markets could provide broader insight into the regional dynamics of calendar anomalies.

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ORGANIZATIONAL SUSTAINABILITY THROUGH A SYSTEMS-BASED FRAMEWORK: THE LEAVITT MODEL PERSPECTIVE

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Purpose: The article aims to demonstrate how sustainability-oriented organizational change can be understood and managed using a system-based perspective, with particular emphasis on the Leavitt Model. By conceptualizing organizations as interdependent systems, the study seeks to explain how coordinated changes across key organizational elements can support the development of sustainable organizations.

Design/methodology/approach: The paper adopts a conceptual and theory-building approach based on a narrative literature review. Interdisciplinary literature on organizational systems, sustainability management, and organizational change was synthesized, and the Leavitt Model was applied as an analytical framework for structuring sustainability-oriented organizational change.

Findings: The study shows that sustainability-oriented organizational change requires coordinated modifications across people, tasks, structure, and technology. Sustainability can be effectively operationalized only through system-wide change rather than isolated initiatives, with the Leavitt Model illustrating how alignment among organizational elements supports long-term sustainability.

Research limitations/implications: The study is conceptual and does not include empirical validation, which limits the generalizability of the findings. Future research may empirically test the proposed framework in different organizational contexts and sectors, as well as examine dynamic interactions among the four elements of the Leavitt Model during sustainability transformations.

Practical implications: The proposed framework offers practical guidance for managers, sustainability officers, and change leaders seeking to embed sustainability across organizational systems. It supports diagnosing misalignments and designing coordinated interventions beyond symbolic or reporting-driven sustainability practices.

Social implications: By promoting a systemic approach to sustainability implementation, the study supports more credible corporate responses to environmental and social challenges, contributing to responsible organizational behavior and long-term societal value creation.

Originality/value: The paper extends the application of the Leavitt Model beyond technological and structural change by explicitly linking it to organizational sustainability. It provides an integrative framework translating sustainability objectives into concrete organizational change mechanisms.

Keywords: sustainable organization; organizational change; Leavitt Model.

Category of the paper: research paper.

1. Introduction

Sustainable development (SD) has become a central imperative for contemporary organizations, driven by intensifying environmental pressures, evolving stakeholder expectations, and increasingly stringent regulatory frameworks. Despite the widespread adoption of sustainability rhetoric, many organizations still struggle to translate sustainability aspirations into effective organizational change. As a result, sustainability is frequently treated as a declarative or symbolic concept rather than a practical and operational one. Common organizational responses remain limited to publishing sustainability reports, adopting green branding, or embedding sustainability commitments in mission statements, while core structures, processes, and everyday practices remain largely unchanged (Rodrigues, Franco, 2019).

Recent research consistently highlights a persistent gap between formal sustainability strategies and their actual implementation. This gap is often attributed to insufficient systemic thinking, fragmented governance mechanisms, weak leadership commitment, and uncertainty regarding how sustainability goals should be operationalized at different organizational levels (Wijethilake, Upadhaya, 2020; Al-Kwafi et al., 2023). Sustainability initiatives are frequently isolated within specific organizational units - such as marketing, or corporate communications - rather than embedded across the entire organizational system. Consequently, sustainability tends to function as an image-building exercise instead of serving as a driver of long-term organizational transformation and resilience (Kostova, Zaheer, 1999; Dyllick, Hockerts, 2002).

The growing body of sustainability literature underscores the need for holistic and integrated approaches to organizational change. Scholars increasingly argue that sustainability cannot be achieved through isolated initiatives or technological fixes alone, but requires coordinated changes in strategy, governance, organizational culture, structures, processes, and employee competencies (George, Schillebeeckx, Liak, 2015; Bocken, Schuit, Kraaijenhagen, 2018). Systems thinking has therefore gained renewed attention as a promising perspective for understanding how sustainability-oriented change unfolds within complex organizations (Williams, Whiteman, Parker, 2019). However, while system-based thinking is frequently advocated at a conceptual level, there remains a shortage of clear, operational frameworks that help organizations understand how to design and manage sustainability-driven change in practice.

That is why the article aims to demonstrate how sustainability-oriented organizational change can be understood and managed using a system-based perspective, with particular emphasis on the Leavitt Model. By conceptualizing organizations as interdependent systems, the study seeks to explain how coordinated changes across key organizational elements can support the development of sustainable organizations.

The value added of this article lies in its integrative and practice-oriented contribution. First, it extends the application of the Leavitt Model beyond its traditional use in technological and structural change by explicitly linking it to sustainability transformation. Second, it offers a coherent analytical framework that translates abstract sustainability goals into concrete organizational design and change mechanisms. Third, by synthesizing recent sustainability and organizational change literature, the article provides actionable insights that can support real-world implementation rather than remaining at a purely conceptual level.

The primary audience of this article consists of organizational practitioners, including top managers, sustainability officers, change managers, and consultants responsible for designing and implementing sustainability initiatives. The proposed framework is particularly relevant for practitioners seeking practical guidance on how to embed sustainability across organizational systems rather than confining it to isolated projects or reporting practices. At the same time, the article also contributes to academic discussions in the fields of sustainability management, organizational theory, and change management by offering a system-based conceptual lens that can inform future empirical research.

The remainder of the article is structured as follows. The next section presents the research approach and methodological assumptions. This is followed by a discussion of organizations as systems and a review of selected system-based organizational models, leading to a justification for adopting the Leavitt Model as the primary analytical framework. Subsequent sections analyze sustainability-oriented organizational change through the four elements of Leavitt's Diamond: people, tasks, structure, and technology. The article concludes with a synthesis of key insights, practical implications for managers, and directions for future research.

2. Methods

This article adopts a conceptual and theory-building research design grounded in a narrative literature review. The methodological objective is not empirical testing, but the development of an integrative analytical framework explaining sustainability-oriented organizational change through a systems perspective, with the Leavitt Model serving as the primary analytical lens.

The study draws on interdisciplinary scholarly literature from the fields of organizational theory, sustainability management, change management, and systems thinking. Relevant publications were identified using academic search engines (e.g., *Scopus*), university library databases, and direct access to peer-reviewed journals and academic monographs. Given the conceptual nature of the research problem and the dispersion of relevant studies across multiple disciplines, the review was not limited to a single database nor conducted as a formal systematic literature review.

A narrative review approach was deliberately selected to allow for interpretative synthesis and theoretical integration. Systematic review protocols were considered but deemed less suitable due to the study's focus on conceptual development, the need to incorporate foundational theoretical works, and the inclusion of diverse publication types (e.g., system theory texts, organizational models, and contemporary sustainability research). While narrative reviews do not rely on formal weighting procedures, the relative influence of the cited studies was reflected through their analytical role in the synthesis: foundational and widely cited theoretical works were used to frame core concepts and assumptions, whereas more recent and specialized studies were employed to refine, illustrate, or contextualize these concepts within the sustainability domain. In this way, theoretical prominence was conveyed through depth of discussion and positioning within the analytical framework rather than through quantitative weighting.

To enhance methodological transparency, explicit inclusion and exclusion criteria guided the selection of literature. Sources were included if they:

- addressed organizations as systems or open systems,
- examined organizational change, technological change, or sustainability-related transformation,
- discussed system-based organizational models (e.g., socio-technical systems, McKinsey 7S, Leavitt's Diamond); or
- contributed to theoretical discussions on sustainability implementation at the organizational level.

Sources were excluded if they:

- focused narrowly on technical solutions without organizational or systemic implications,
- addressed sustainability solely at the macro or policy level without organizational relevance; or
- lacked academic rigor, peer review, or theoretical grounding.

The analytical procedure consisted of three sequential stages. First, key system-based organizational models were identified and comparatively analyzed to clarify how different frameworks conceptualize internal organizational elements and their interdependencies. Second, the concept of the sustainable organization was theoretically elaborated through a synthesis of sustainability and organizational change literature, with the aim of clarifying its

defining characteristics, underlying assumptions, and key dimensions at the organizational level, without reference to specific analytical models. This stage focused on explaining how sustainability is operationalized within organizations as a system-wide and long-term process encompassing environmental, social, and economic objectives.

Third, drawing on the insights derived from both the comparative analysis of system-based models and the conceptual discussion of organizational sustainability, the Leavitt Model was applied as the primary analytical framework. The model was used to structure and present sustainability-oriented organizational change by examining how coordinated and mutually reinforcing modifications occur across its four core, interdependent elements - people, tasks, structure, and technology. This application enabled a systematic analysis of how sustainability objectives are translated into organizational practices and embedded across the organizational system. By explicitly emphasizing the mutual interdependencies among organizational elements, this approach ensures internal coherence of the analysis and is consistent with system theory assumptions that changes in one element inevitably affect the others.

Overall, the adopted methodology supports a theoretically grounded and practically oriented exploration of organizational sustainability. By combining a narrative literature review with a system-based analytical framework, the study provides a coherent basis for understanding how sustainability can be operationalized through integrated organizational change rather than isolated initiatives.

3. Organization as a System

In management and organization theory, the concept of a system refers to a set of interrelated and interdependent elements that function together as a coherent whole in order to achieve specific goals. A system is defined not only by its individual components, but also by the relationships and interactions among them (von Bertalanffy, 1968). Consequently, changes in one element of the system tend to affect other elements, as well as the overall system performance. To ensure coherent functioning and to prevent dysfunctions, the goals of the system must be aligned and synchronized with the objectives of its individual components (Zhao, Zhang, 2013).

This systemic perspective provides a useful foundation for understanding organizations, which are increasingly conceptualized as open systems that must continuously adapt to changes in their external environment in order to survive and develop (Scott, Davis, 2000; Daft, 2015). Such openness implies ongoing interactions with the environment and sensitivity to economic, social, technological, and environmental pressures. One of the most significant contemporary environmental trends shaping organizational functioning is SD, which imposes new expectations regarding responsibility, resource use, and long-term value creation.

Consequently, it becomes essential to understand how changes in the external environment - such as sustainability-related regulations, stakeholder expectations, or technological innovations - affect the configuration and alignment of internal organizational elements. Therefore, understanding which internal elements constitute an organization and how they are interrelated is crucial, as it provides the foundation for explaining adaptation processes and for managing change in a coherent and effective manner.

Viewing organizations as systems has led to the development of several system-based models. One of the foundational approaches is the Socio-Technical Systems Model (STS). It conceptualizes organizations as composed of two interdependent subsystems: the social subsystem (people, roles, relationships, culture) and the technical subsystem (tools, technologies, workflows). The core assumption of this approach is that organizational effectiveness depends on the joint optimization of both subsystems rather than on the improvement of one at the expense of the other (Trist, Bamforth, 1951).

The STS perspective has been widely applied in studies on work design, technological change, and digital transformation. Later authors expanded this model to analyze the impact of information systems and automation on organizational performance and employee well-being (Cherns, 1976; Pasmore, 1988). In contemporary research, socio-technical thinking is frequently used in the context of Industry 4.0 (Baxter, Sommerville, 2011).

Building on this systemic logic, broader integrative frameworks have been developed to capture a wider range of organizational elements and their interdependencies. One such approach is the McKinsey 7S Model, which presents organizations as systems consisting of seven interdependent elements: strategy, structure, and systems, as well as skills, style, staff, and shared values (Waterman, Peters, Phillips, 1980).

Strategy represents the organization's plans and actions to improve its position relative to competitors, for example through cost leadership, delivery efficiency, high perceived product or service quality, or achieving defined sales and service targets. It reflects the manner in which the organization intends to create unique value. Next, systems encompass all procedures, both formal and informal, that enable the organization to function, such as quality management systems, training programs, accounting procedures, and budgeting systems, while structure refers to the formal arrangement of parts within the organization, ensuring coordination and division of tasks. This can take the form of functional, product-based, market-based, geographic, or strategic business unit structures, defining dimensions of specialization, integration, and centralization. Skills constitute the dominant and key capabilities or functions that support the other elements, including organizational competencies, strengths, employee skills, and forms of knowledge aggregation. Style describes the adopted behaviors and management styles of leaders, including symbolic and cultural practices within the organization. Staff refers to the organization's human resources, considered both in a hard perspective (evaluation systems, payroll tables, formal training programs) and a soft perspective (morale, attitudes, motivation, and behavior), including processes of socialization, onboarding,

and career management. Finally, shared values are the overarching goals and philosophy of the organization, representing guiding principles, aspirations, and informal norms that extend beyond formal objectives. They shape the organization's activities and are common to all components, reflecting its collective mindset.

The 7S framework has been extensively used in strategic management, organizational diagnostics, and change management research. It has been applied to analyze strategic alignment (Higgins, 2005) and organizational transformation (Park, Yoo, Lee, 2021). Its strength lies in providing a holistic yet practical tool for assessing internal consistency within organizations, allowing scholars and practitioners to understand how hard and soft elements interact and influence overall organizational effectiveness.

Polish management literature offers complementary perspectives on organizational systems. Bielski (1997) proposed a model consisting of five interrelated subsystems: the goal and values subsystem, shaped by individual employee personalities, subcultures of small groups, personal goals and values, and the overall organizational culture; the psychosocial subsystem, consisting of people and groups interacting in day-to-day activities; the technical subsystem, encompassing techniques and technology used in the organization; the structure subsystem, which defines relationships among all components, task division, and coordination; and the management subsystem, which integrates all other subsystems and maintains balance between the organization and its environment. Similarly, Krzyżanowski (1999) conceptualizes the organization as a system composed of interrelated internal elements embedded in continuous interaction with the environment. At its core lies the management (steering) subsystem, which defines the mission, strategy, and goals and regulates organizational activity, while the structural subsystem enables the transformation of inputs into outputs by integrating input logistics, transformation processes, and output logistics, thereby coordinating tasks, information flows, and resource utilization. Organizational functioning is grounded in the interaction between human resources, understood as carriers of creative potential, and natural as well as technical–technological resources, which together constitute the material and technological base of operations. Ongoing exchanges with the environment, supported by feedback mechanisms, ensure system balance, adaptability, and the effective transfer of goods and services, highlighting the dynamic interdependence of management, structure, resources, and people in achieving organizational goals.

Finally, the Leavitt Model (Leavitt's Diamond) provides a parsimonious yet analytically robust framework for examining internal organizational systems. In contrast to more complex and multidimensional models, such as the McKinsey 7S framework or broader subsystem approaches, Leavitt's model reduces organizational complexity to four core, mutually dependent elements: tasks, people, structure, and technology. This reduction does not oversimplify organizational reality; rather, it enhances analytical clarity by making causal interdependencies between elements more explicit and empirically traceable (Markus, 1983).

The model is particularly well suited for analyzing organizational change, as it explicitly assumes that any modification in one element inevitably induces adjustments in the remaining elements. This assumption aligns closely with system theory principles and with contemporary challenges faced by organizations adapting to sustainability-related pressures, such as regulatory change, technological innovation, and evolving stakeholder expectations. As sustainability transformations typically require simultaneous changes in work processes, technologies, organizational structures, and employee competencies, the Leavitt Model offers a coherent framework for capturing these multidimensional adjustment processes in an integrated manner (Zha, Xu, 2009; Qin et al., 2023).

Table 1 presents a comparison of selected system-based organizational models, highlighting their core elements, analytical focus, and relative complexity. This overview illustrates how different models conceptualize interdependencies within organizations and provides a clear rationale for selecting the Leavitt Model as a practical framework for studying sustainability-driven organizational change.

Table 1.
Comparison of selected system-based organizational models

Model	Core Elements / Subsystems	Analytical Focus	Level of Complexity
Socio-Technical Systems (STS)	Social subsystem (people, roles, culture) and technical subsystem (technology, workflows)	Joint optimization of social and technical dimensions of work	Low–moderate
McKinsey 7S Model	Strategy, structure, systems, skills, style, staff, shared values	Internal alignment between hard and soft organizational elements	High
Krzyżanowski's System Model	Management (steering), structure, human resources, natural resources, technical - technological resources, logistics	Organization as a purpose-oriented open system embedded in the environment	High
Bielski's Subsystem Model	Goals and values, psychosocial, technical, structural, management subsystems	Internal coherence of organizational subsystems and balance with environment	High
Leavitt's Diamond	Tasks, people, structure, technology	Mutual interdependence of core organizational elements	Low

Source: Own elaboration.

The Leavitt Model is adopted as the primary analytical framework in the following sections due to its conceptual clarity, methodological flexibility, and proven applicability in studies of technological and organizational change. However, despite its analytical strengths, it has rarely been applied to sustainability-oriented organizations, as existing research has focused primarily on technological change and information systems without systematically incorporating long-term environmental and social objectives. This gap justifies embedding the Leavitt Model within a sustainability-oriented perspective, forming the basis for analyzing sustainability-driven organizational change.

4. Sustainable Organization: Theoretical Discussion

SD, understood as a more balanced and lasting managerial approach (Pietrzak, 2025), has become a central response to contemporary economic, environmental, and social challenges (Rahman et al., 2022; Purvis et al., 2018). In a world characterized by constant change, intensified by the rapid pace of technological change and deep structural transformations, comprehensive, long-term planning and management are increasingly challenging. This, in turn, leads organizations to seek more balanced and consistent paths of development and to implement more sustainable organizational systems, management practices and business models (Schaltegger et al., 2012; Kozar, Oleksiak, 2022). Under these conditions, the concept of sustainable organization has been recognized and broadly accepted, providing an important framework for understanding how organizations can create value through their responsible and future-oriented actions (Rahman et al., 2022; León, 2013; Tavanti, 2023). Also, there is a growing need to move beyond a general corporate-level commitment to sustainability towards concrete, systemic measures implemented across the organization in everyday operations. This, in turn, requires a clearer and more nuanced understanding of what being a sustainable organization actually entails.

An important milestone in the reorientation toward sustainable solutions was The UN World Commission on Environment and Development's report *Our Common Future* (also commonly referred to as the Brundtland Report), which defined SD as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). This definition later became a key reference point for broader sustainability frameworks, such as the triple bottom line concept: profit-people-planet (Elkington, 1997; 2004) or a more recent and broader perspective of applying SD principles to five areas: people, planet, prosperity, peace and partnership (Kasztelan, 2022; Pietrzak, 2025). The concept of SD shifted organizations' attention from short-term economic growth to responsibility for both present and future generations, emphasizing the need for intergenerational (Clark, Miles, 2021; Ketprapakorn, Kantabutra, 2022; Kaul et al., 2025) and distributive equity. Rather than focusing solely on maximizing profit, businesses increasingly adopt a broader perspective, viewing the organization as part of a wider ecosystem and taking into account interdependent operations, value networks, and diverse stakeholders (Rahman et al., 2022).

As organizations have shifted their overall orientation and management approach, the very concept of sustainable organization has also evolved (Graczyk-Kucharska, 2025). Until around 2000, a sustainable organization was understood as "an entity that integrates economic, environmental, and social development opportunities into its business strategies, with a long-term orientation that meets current needs without compromising those of future generations" (Soyka, 2012; León, 2013 after: Graczyk-Kucharska, 2025). After 2000, definitions

increasingly emphasized the integration of economic, environmental, and social goals in strategies, operations, and project portfolios (Turan et al., 2008), stressing that sustainable organizations can effectively manage their resources, achieve long-term financial and operational stability and proactively manage risk and innovation, applying SD principles (Soyka, 2012). León (2013) further stresses that a sustainable organization not only adapts its operational practices to SD principles but also develops new strategies that support innovation and the organization's adaptive capabilities. In more recent publications, a sustainable organization is one whose “production, organizational, and marketing processes follow sustainable development principles, using environmentally friendly technologies, reducing waste, ensuring energy efficiency, and managing resources sustainably across social, natural, and economic pillars” (2025, p. 29). It is also described as an organization that pursues strategic SD beyond mere economic growth, and “prioritizes social inclusion, equality, and environmental sustainability to achieve success in the global economy” (Graczyk-Kucharska, 2025, p. 29), and an entity whose management is oriented toward the integration of sustainability principles into corporate culture, communication as well as performance and quality standards (Pietrzak et al., 2025). Increasingly, authors and researchers emphasize the practical and applicable aspects of an SD three-dimensional framework, stressing that a sustainable organization integrates economic, social, and environmental goals across the company, in both its daily operations and its long-term development strategies.

Due to its socio-economic importance, the business sector is identified as one of the key participants in achieving SD. Organizations are an integral component of modern societies and, as Lozano (2018, p. 1157) points out, “they are subsystems of a larger environmental system”. As Błach (2025, p. 65) stresses, “each economic entity can implement sustainable development goals in a manner tailored to its scale and specific operations”. It is important to note that the triple bottom line (profit–people–planet) translates the macro-level idea of SD into a business-oriented framework (Levi-Jakšić et al., 2018). It implies an authentic shift from a corporate orientation focused on financial results to three equally important dimensions: economic, social, and environmental. For an organization to be considered sustainable, the change needs to be embedded in corporate strategy, governance, decision-making, and operations (Das et al., 2025), not pursued as secondary, marketing-driven initiatives or a peripheral activity (Putra et al., 2025). The three dimensions shape both the overall performance and legitimacy of the sustainable organization (León, 2013; Terlecka, 2014, after: Pietrzak, 2025). In this perspective, a sustainable organization is accountable not only to its management and shareholders, but also to employees, customers, local communities, and the ecosystems it affects. It integrates societal fairness, economic effectiveness, and environmental performance into corporate practices (Varsei et al., 2014, after: Rahman, 2022), and SD is seen as “a comprehensive approach that guides the firm to limit harm and create economic, social, and environmental value”, not merely as “a way to measure and report a company’s business, social, and environmental performance” (Žak, 2015, p. 254).

As Tasleem et al. (2017, p. 3) indicate, “corporate management is keen to adopt a roadmap or a framework that can be useful in the identification, management and measurement of the drivers and can lead to desired outcomes relating to sustainable performance”. Building on this need, the authors propose a system-oriented framework to operationalize sustainability at the organizational level, shifting from general declarations to measurable solutions and ensuring commitments are met through implementation. The authors’ perspective on a sustainable organization, which is presented below, reflects a broader understanding of the concept as a system that, in line with the SD principles, creates economic value, minimizes negative environmental impacts, and enhances human well-being.

5. The Sustainable Organization: A Systems Perspective

Organizational sustainability requires a holistic and systemic approach in which changes are not implemented in isolation but encompass the entire socio-technical system of the organization. Sustainable organizations are those that can adapt to environmental, technological, and social changes while maintaining alignment between their goals, structures, processes, and people.

Evidence from public sector information systems projects shows that sustainable outcomes depend on aligning technological change with organizational structures, work practices, and human capabilities (Heiskanen et al., 2013). Similarly, lean production initiatives demonstrate that improvements in operational efficiency require synchronized adjustments in organizational roles, task design, and supporting technologies (Zha, Xu, 2009). Furthermore, successful change management relies on active employee engagement, clear communication, and strong leadership support (Cork, 2005).

Overall, organizational sustainability can only be achieved through an integrated, system-wide approach to change - one that considers the mutual interdependencies among people, tasks, structures, and technologies. In this context, Leavitt’s model provides a practical and analytically robust framework for understanding and managing such holistic transformations.

In the following sections, this article will provide a detailed analysis of the changes that must occur within each element of Leavitt’s model, highlighting how coordinated adaptations across tasks, people, structures, and technologies can support the development of sustainability-oriented organizations.

5.1. The role of people in sustainability-oriented organizational transformation

From a systems perspective, people constitute the central element of the organization, as they interpret strategic goals, make decisions, and translate sustainability principles into everyday practices. Consequently, the development of employees' and leaders' competencies is a key prerequisite for effective sustainability-oriented transformation. Mentoring and coaching play a particularly important role in this process as tools for human capital development. Mentoring provides long-term, relationship-based support that facilitates knowledge transfer, value internalization, and leadership development, whereas coaching focuses on structured, time-bound goals aimed at improving performance and effectiveness (Irwin, 2005; Basher, 2025). Both practices have been shown to increase employee engagement, retention, and job satisfaction, thereby fostering a culture of continuous learning and development within organizations (Smith, Lynch, 2014; Basher, 2025).

In the context of sustainability, mentoring and coaching also support inclusive leadership, facilitate the integration of new employees into organizational culture, and improve communication and access to senior leadership positions (Smith & Lynch, 2014; Singha, 2024). Furthermore, mentorship has been linked to enhanced innovative behavior and proactive engagement, crucial for organizations operating in rapidly changing environments (Baran, Clutterbuck, 2023). Coaching specifically can help individuals develop self-awareness, resilience, and adaptability, which are widely recognized as key competencies of the future workplace, especially in sustainability-driven roles where change is continuous and unpredictable.

The growing use of virtual platforms and artificial intelligence (AI) has further expanded the scope of these practices, making them more accessible, scalable, and personalized, which supports the widespread development of sustainability-related competencies across the organization (Basher, 2025). Recent research on AI in coaching suggests that generative AI tools can augment traditional coaching by enhancing personalization and providing real-time feedback, thereby supporting continuous learning and development at scale (Diller, Stenzel, Passmore, 2024). These technology-enhanced approaches also align with broader trends in digital-enabled human resource practices that emphasize agile learning, collaboration, and data-driven decision making as strategic enablers of sustainable growth.

By integrating mentoring and coaching into organizational strategies, companies not only build individual capacity but also foster collective competencies - such as ethical leadership, systems thinking, and collaborative problem solving - that are essential for navigating complex sustainability challenges. This holistic development supports a resilient workforce capable of driving long-term sustainable value creation in dynamic economic and social contexts.

5.2. The role of tasks in sustainability-oriented organizational transformation

Within Leavitt's model, organizational tasks are closely linked to the organization's mission, vision, and strategic objectives. In a sustainable organization, the "green" mission statement plays a pivotal role by integrating economic goals with environmental and social responsibility. Mission statements communicate an organization's commitment to sustainability to its stakeholders, strengthening consumer identification with the company and positively influencing purchasing decisions (Ding et al., 2025). Sustainability-oriented missions may also serve as a source of competitive advantage and long-term value creation for customers and other stakeholders (Ding et al., 2025; King et al., 2010). However, the effectiveness of a green mission statement depends on its relevance and consistency with actual organizational practices. Regular updates of mission statements are necessary to reflect changes in the socio-economic environment and internal strategic priorities, thereby preventing sustainability from being reduced to a purely symbolic or image-building exercise (King et al., 2010; Yozgat, Karataş, 2011).

In practice, sustainable organizations redesign tasks to align daily activities and responsibilities with environmental, social, and long-term economic goals. Routine tasks are structured to minimize resource consumption, reduce waste, and limit negative environmental impact - for example, implementing energy-efficient processes or adopting circular material flows. Greater emphasis is placed on cross-functional and collaborative tasks, enabling holistic problem-solving related to sustainability, such as joint teams working on eco-innovation or sustainable supply chain solutions. Tasks are also designed to foster continuous improvement and learning, including process optimization, sustainable service design, and experimentation with environmentally friendly technologies. Decision-related tasks explicitly incorporate sustainability criteria, such as evaluating carbon footprints, ensuring ethical sourcing, and assessing social responsibility implications of business choices.

By integrating these practices, organizations ensure that sustainability is not only a strategic statement but a guiding principle embedded in everyday operations, driving both long-term value creation and positive environmental and social outcomes.

5.3. The role of structure in sustainability-oriented organizational transformation

Organizational structure shapes how activities are coordinated and how information flows within a system. In sustainable organizations, flexible structures and cross-functional teams are increasingly important, as they enable the integration of environmental, social, and economic considerations into decision-making and operational processes.

In practice, organizations may have departments or positions such as a President, Chief Sustainability Officer (CSO), and heads of Environmental, Economic, and Social Sustainability. The President sets the overall sustainability strategy and policy, while the CSO translates these strategic goals into actionable plans, monitors performance through

comprehensive reports, and communicates with key stakeholders. Operational responsibilities are delegated to the heads of environmental, social, and economic sustainability, who oversee teams that implement initiatives, monitor progress, and prepare targeted reports. These teams work closely with other units to coordinate sustainability actions, collect data, and ensure follow-up, ensuring that initiatives are effectively embedded across the organization.

This approach emphasizes both vertical and horizontal alignment. Vertical alignment ensures that sustainability objectives flow consistently from top management to operational teams, while horizontal alignment promotes collaboration among environmental, social, and economic functions. Sustainability teams play a key role in facilitating knowledge sharing, collaborative problem-solving, and the development of interpersonal relationships, all of which are essential for team effectiveness and viability (Kalabina, Belyak, 2020; Demir, Ergün, 2023).

Effective sustainability teams integrate diverse competencies, encourage cross-functional collaboration, and foster a culture of continuous improvement and organizational learning (Kalabina, Belyak, 2020; Messaoudene, 2019). Research also shows that team performance improves when teams operate in an environment characterized by organizational justice, trust, and active employee participation, leading to greater stability, resilience, and higher performance levels (Demir, Ergün, 2023).

By combining hierarchical oversight with cross-functional collaboration, organizations can respond dynamically to sustainability challenges, align ESG objectives with operational activities, and engage all levels - from strategic decision-makers to operational teams - in creating long-term value.

5.4. The role of technology in sustainability-oriented organizational transformation

Technology constitutes a critical enabler of sustainability implementation within organizations. Green technologies - such as renewable energy solutions, energy-efficient systems, and environmental monitoring tools - allow organizations to reduce their environmental footprint while improving resource efficiency. Research indicates that green technology innovation contributes positively to corporate Environmental, Social, and Governance (ESG) performance by reducing environmental management costs and increasing employee engagement in pro-environmental activities (Wang, Yang, 2025; Zong, 2024).

Digital transformation further strengthens the relationship between ESG performance and green technology innovation, acting as a key moderating factor (Xu, He, 2025). ESG reporting, particularly when supported by digital technologies, artificial intelligence, and blockchain solutions, enhances transparency, accountability, and stakeholder trust (Soomro et al., 2025; Khamitdkhanovich et al., 2025). Moreover, strong ESG performance encourages further investment in green innovation, creating a positive feedback loop between sustainability outcomes and long-term organizational competitiveness (Zhao et al., 2025).

However, the sustainability implications of technology adoption are not exclusively positive. Efficiency improvements enabled by green and digital technologies may give rise to rebound effects, whereby reduced costs and increased productivity lead to higher overall resource consumption, partially offsetting environmental gains. In addition, the deployment of digital technologies can introduce unintended sustainability trade-offs, including increased energy demand, electronic waste generation, and social challenges related to skills polarization and data governance (Yerushalmi, Saha, 2025).

In this context, organizations that integrate green technology and digital tools into their operations while critically assessing and managing these potential side effects are better positioned to achieve sustainable performance goals. The adoption of such technologies not only addresses regulatory and environmental pressures but also fosters innovation, improves operational efficiency, and strengthens the organization's reputation among stakeholders. Consequently, technology serves as both a practical instrument for implementing sustainability initiatives and a strategic driver of long-term competitive advantage, provided that its application is guided by a systemic and holistic sustainability perspective rather than a purely technological one.

To ensure that technology-driven sustainability initiatives remain aligned with other organizational elements within the Leavitt Model, organizations should systematically monitor organizational-level indicators capturing the coherence between people, tasks, structure, and technology. Such metrics enable managers to assess whether sustainability-oriented technologies genuinely support strategic goals, are embedded in daily operations, and are reinforced by appropriate competencies and structures, rather than generating isolated or counterproductive effects. Table 2 presents exemplary indicators that allow organizations to evaluate this alignment in a structured and measurable way.

Table 2.

Organizational-level indicators for assessing sustainability alignment within the Leavitt Model

Leavitt Model element	Example organizational-level indicators / metrics
People	• Percentage of employees trained in sustainability-related digital/green technologies. • Employee sustainability engagement index (survey-based). • Share of leadership roles with sustainability or ESG-related performance objectives. • Use rate of AI-supported mentoring/coaching tools.
Tasks	• Percentage of core processes with embedded sustainability criteria (e.g. carbon, social impact). • Number of sustainability-related KPIs included in operational dashboards. • Share of projects assessed using life-cycle or ESG-based evaluation tools.
Structure	• Existence of formal sustainability governance roles (e.g. CSO, ESG committees). • Frequency of cross-functional sustainability meetings or projects. • Degree of vertical ESG goal alignment. • Clarity of sustainability-related reporting lines.
Technology	• Reduction in energy use / emissions per unit of output enabled by technology. • Share of IT and digital investments classified as green or ESG-supporting. • Quality and completeness of digital ESG reporting (audit or assurance scores).

Source: Own elaboration.

6. Summary

The article addresses a critical and increasingly relevant challenge faced by contemporary organizations: the persistent gap between formally declared sustainability strategies and their effective implementation in everyday organizational practices. Although sustainability has become a widely adopted managerial concept, many organizations continue to approach it in a fragmented and symbolic manner, limiting their efforts to reporting, branding, or isolated environmental initiatives without introducing meaningful changes to core organizational systems.

In response to this problem, the article adopts a systems-based perspective on sustainability-oriented organizational change, positioning sustainability not as a standalone initiative but as a comprehensive, organization-wide transformation. The central premise of the study is that long-term organizational sustainability can only be achieved through the coherent alignment of key organizational elements and their mutual interdependencies. To operationalize this perspective, the authors employ the Leavitt Model as an analytical framework, conceptualizing organizations as systems composed of four interrelated elements: people, tasks, structure, and technology.

The main objective of the article - namely, to demonstrate how sustainability-oriented organizational change can be understood and managed using a systems-based perspective with particular emphasis on the Leavitt Model - has been successfully achieved. The authors clearly articulate the theoretical foundations of systems thinking, justify the selection of the Leavitt Model, and consistently apply it throughout the analysis of sustainability-oriented change.

By systematically examining each element of the model and highlighting their interdependencies, the article effectively shows how sustainability can be operationalized as an integrated organizational transformation rather than as a set of isolated or symbolic activities. The conceptual framework directly addresses the research objective and provides a clear analytical logic that links sustainability goals to organizational design and change processes.

The article makes several important theoretical and practical contributions. First, it extends the application of the Leavitt Model beyond its traditional focus on technological and structural change by explicitly integrating sustainability objectives into the model. This represents a meaningful theoretical advancement, as sustainability has rarely been analyzed through this particular systems-based framework.

Second, the study offers an integrative and practice-oriented perspective that bridges the gap between abstract sustainability concepts and concrete organizational change mechanisms. By translating sustainability into coordinated changes in people, tasks, structure, and technology, the article provides managers, sustainability professionals, and change leaders with a clear diagnostic and design tool for sustainability implementation.

Third, by synthesizing recent literature from multiple disciplines, the article contributes to the consolidation of fragmented research streams on organizational sustainability and change management. This integrative approach strengthens the conceptual foundations of sustainability-oriented organizational research and lays a solid basis for further empirical investigation.

Despite its contributions, the article has several limitations. The primary limitation is its conceptual nature and the absence of empirical validation. As the framework is developed through a narrative literature review, the findings cannot be generalized without further empirical testing. Additionally, the narrative review methodology, while suitable for theory-building, involves a degree of subjectivity in literature selection and interpretation.

Another limitation is that the article does not provide a systematic comparison of the explanatory power of the Leavitt Model with alternative sustainability-oriented organizational frameworks (e.g. socio-technical systems, the McKinsey 7S framework, or ESG- and capability-based models). Although these frameworks are acknowledged in the theoretical background, their relative strengths and limitations in explaining sustainability-oriented organizational change are not explicitly contrasted. Addressing this gap would strengthen the theoretical positioning of the Leavitt Model and clarify its distinctive analytical contribution.

Future research should therefore focus on empirically testing the proposed framework in different organizational contexts, industries, and institutional environments. Quantitative studies could examine the relationships between the alignment of Leavitt's elements and sustainability performance, while qualitative case studies could explore the dynamic interactions among people, tasks, structure, and technology during sustainability transformations.

Further research could also investigate longitudinal aspects of sustainability-oriented change, analyzing how system-wide alignment evolves over time and how organizations manage tensions and trade-offs between sustainability objectives and short-term performance pressures. In addition, comparative studies that explicitly evaluate the Leavitt Model alongside other sustainability-oriented frameworks could provide deeper insights into their respective explanatory power and practical applicability. Finally, integrating the Leavitt Model with other sustainability and performance frameworks - such as ESG metrics or quality management models - could further enrich the understanding of sustainable organizational transformation.

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THE INTEGRATION OF ESG STRATEGY WITH THE ENTERPRISE'S BUSINESS MODEL – THE PERSPECTIVE OF MANAGERS IN POLAND

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Purpose: The article aims to examine how managers in Poland perceive the process of integrating ESG (Environmental, Social, Governance) strategies with the company's business model, with particular emphasis on motivations, benefits, barriers, and the role of this integration in shaping the competitive advantage.

Methodology: A mixed methods approach was employed, combining quantitative and qualitative research and triangulating the results. Quantitative section: a custom-designed questionnaire (Google Forms) encompassing four sections (company metrics/characteristics; ESG integration into the business model; integration impact; barriers and challenges). Sampling: purposive with elements of snowball sampling (LinkedIn). Sample: N = 28 respondents (board members, directors/managers, specialists) from various industries (including construction/real estate, manufacturing, services, energy, finance, agriculture). Qualitative section: 5 in-depth individual interviews (IDIs) with managers responsible for ESG implementation; a script of 17 open-ended questions; content analysis to identify common patterns and categories.

Findings: Enterprises in Poland are in a transition phase from declarative to strategic-operational ESG implementation; senior management plays a key role. (2) The most strongly observed impact of ESG concerns reputation and customer loyalty, while the financial effects are indirect and long-term. (3) In capital-intensive industries, ESG strengthens access to capital and risk reduction; in services/manufacturing – the offer and customer relationships. (4) The identified barriers fall into three groups: cultural, economic, and competency-based; in the quantitative study, the most frequently indicated barriers were: unclear regulations, insufficient competencies, low employee engagement, and limited financial resources.

Research limitations/implications: The study's exploratory nature requires managerial self-reports, which limit the objectivity of conclusions. The sample is limited to companies that operate in Poland, which makes it difficult to generalize to other countries. There is no thorough quantitative investigation into the correlation between ESG integration and financial/non-financial indicators, or an evaluation of the quality of ESG reports (risk of greenwashing). Quantitative research (statistical/econometric), international comparisons, and longitudinal studies are recommended.

Practical implications: ESG should be regarded as a strategic component rather than merely a reporting obligation. It enhances market credibility, facilitates access to financing, supports effective risk management, and can reduce the cost of capital. Achieving this requires

developing managerial competencies in ESG reporting and auditing, along with improving data verifiability.

Social implications: Greater transparency and broader stakeholder inclusion enhance social trust, foster sustainable development and environmental stewardship, and encourage responsible behaviors among consumers and investors.

Originality/value: This article offers one of the first comprehensive cross-sectional analyses of ESG integration into business models from a managerial perspective in Poland. It combines stakeholder theory and the resource-based view (RBV) with empirical evidence derived from surveys and in-depth interviews (IDI), revealing industry-specific differences and implementation mechanisms through methodological triangulation.

Keywords: ESG; ESG integration; business model; strategic management; stakeholder theory; resource-based view (RBV); sustainable development; corporate governance; Poland.

Category of the paper: Scientific research article.

1. Introduction

Modern enterprises operate in a rapidly evolving economic, social, and regulatory environment, where sustainable development practices are gaining increasing significance. Within this context, the concept of ESG (Environmental, Social, and Governance) plays a pivotal role, encompassing three dimensions of organizational responsibility: environmental, social, and corporate (Kobiela-Pionnier, 2023). ESG extends the earlier notion of corporate social responsibility (CSR); however, unlike CSR, it represents a broader and more systemic framework that integrates ethical, ecological, and social considerations with a company's economic objectives (Łudzińska, 2024; Morrison, 2021).

Initially, ESG reporting was voluntary, but the evolution of EU regulations—particularly Directive 2014/95/EU and the Corporate Sustainability Reporting Directive (CSRD)—has transformed it into a legal obligation for an expanding group of enterprises (Regulation (EU) No. 575/2013 of the European Parliament and of the Council, 2013). These regulatory frameworks not only mandate the disclosure of non-financial information but also establish new standards of strategic management grounded in transparency and accountability. The implementation of ESG principles therefore assumes a dual character: regulatory and managerial. On the one hand, it ensures compliance with formal requirements; on the other, it enables organizations to realize long-term economic, reputational, and relational benefits (Mikołajczyk, 2023; Śledzik et al., 2023). Empirical studies demonstrate that integrating ESG reporting with corporate strategy enhances competitive advantage by strengthening reputation, increasing stakeholder trust, improving risk management, and optimizing resource utilization (Ślazińska-Kluczek, Brzezek, 2024; Wyrwich-Płotka, 2024). Nevertheless, the Polish context of ESG integration remains relatively underexplored. Prior research has primarily concentrated on regulatory frameworks and theoretical foundations, often neglecting the managerial perspective—that is, the viewpoint of those directly responsible for shaping and executing ESG

strategies within organizations (Freeman, 1984; Deloitte, 2023). Accordingly, this article seeks to examine how managers in Poland perceive the integration of ESG strategy into corporate business models. The study aims to identify the key motivations, perceived benefits, and barriers associated with incorporating ESG into strategic management practice. In doing so, it addresses an existing research gap concerning the strategic dimension of ESG in Polish enterprises and contributes to a more comprehensive understanding of its role in building competitive advantage in the contemporary economy.

2. The strategic Dimension of ESG Implementation

ESG (Environmental, Social, and Governance) reporting encompasses two aspects: the legal aspect – the obligation for companies to disclose information on the impact their activities have on these three areas, as defined by law; and the governance aspect – the benefits that companies reporting ESG derive – even without a formal legal obligation – from integrating ESG reporting, which signifies a comprehensive recognition of the principles of sustainable development in achieving their business goals. The governance aspect is therefore broader than the legal aspect, but it must take into account existing legal regulations. Therefore, these aspects should be given some consideration first.

The basis for legal regulations relating to ESG is seen in the strong growth in the mid-2000s of interest in non-financial reporting related to environmental, social and corporate governance issues, which quickly became an integral component of reporting by large listed companies (Kobiela-Pionnier, 2023). The concept of non-financial ESG reporting was preceded by the strong promotion of the concept of Corporate Social Responsibility (CSR) in Western economies. ESG is considered a more advanced variant of CSR. Both are critically assessed from the perspective of economic doctrine, with ESG considered "more dangerous" because its promotion and "implementation" are spreading increasingly widely and permeating legal and business language, the media, and public discourse at an unprecedented rate.[...] can in fact be read as a kind of alternative to capitalism, if not a tool aimed against capitalism in the sense we know it so far", because "it undermines [...] the axiological and philosophical foundations of the Western economic system" (Olszak, Stokłosa, 2025). There is no need to delve into the substance of these objections. Broadly speaking, they stem from the fact that the ESG concept is about "how governance structures can be changed to maximize stakeholders' well-being", which is fundamentally at odds with the established concept of a company's interest (corporate interest), which is "the result of its individual shareholders, not a broader circle of stakeholders" (Olszak, Stokłosa, 2025). In other words, ESG is changing the paradigm of how commercial companies, corporations, and private law entities operate. These companies should, in principle,

multiply their shareholders' assets rather than concern themselves with the well-being of relevant, legally designated groups of stakeholders.

These reservations should be noted as well as stress out that they do not change the fact that the implementation of the ESG reporting concept is becoming increasingly common among the executive bodies subject to management responsibility. The issues relating to ESG reporting were regulated in The European Union law and then implemented into the national legal systems of individual Member States. This was the result of the process initiated by the adoption of Directive 2014/95/EU of the European Parliament and of the Council of 22 October 2014 amending Directive 2013/34/EU in regards to the disclosure of non-financial and diversity information by certain large undertakings and groups (Regulation (EU) No 575/2013 of the European Parliament and of the Council, 2013), which no longer applies from 1 January 2024. It obliged large businesses employing over 500 people (listed companies, banks and insurers) to disclose data regarding non-financial aspects of their operations, i.e. environmental, social and corporate governance data. The process of standardizing ESG reporting continued in subsequent years and was progressive in nature, in the sense that this obligation was extended to successive groups of enterprises.

The CSRD is key to implementing the ESG reporting paradigm. It not only regulates in detail the specific aspects of data disclosure covered by this requirement but also establishes a timetable for extending this requirement to successive groups of companies. It should be emphasized that the schedule presented below refers only to regulatory compliance in the area of ESG reporting and does not determine the degree of its strategic integration with the business model of companies, which is a separate dimension analyzed later in this article.

This timetable, taking into account the temporal modifications introduced after the CSRD was adopted, is presented in Table 1.

Table 1.
The ESG reporting obligation implementation schedule

Stage/company subject to the obligation	Criteria	Original date according to CSRD	New date after CSRD modifications
Stage 1: large listed entities	At least two out of three: 1) 250 employees; 2) EUR 80 million in revenue; 3) EUR 40 million in total assets.	From 2025 for the 2024 financial year	
Stage 2: large unlisted entities	At least two out of three: 1) 250 employees; 2) EUR 80 million in revenue; 3) EUR 40 million in total assets.	From 2026 for the 2025 financial year	From 2028 for the 2027 financial year

Cont. table 1.

Stage 3: SMEs (public interest entities, including listed companies, small non-complex financial institutions (which are public interest entities but are not micro-entities), captive insurance and captive reinsurance undertakings meeting the CRR criteria) and certain non-EU companies (without a headcount threshold, operating in the EU under franchise or licensing agreements, if the royalties amounted to EUR 22.5 million in the financial year and the worldwide net sales revenues exceeded EUR 80 million	1) more than 10 employees, 2) total revenues of EUR 900,000; 3) total assets of more than EUR 450,000	From 2027 for the 2026 financial year	From 2029 for the 2028 financial year

Source: own study based on the CSRD Directive; Pantazi, 2024, pp. 145-160; Kowalska, Wysocki, 2025, pp. 45-61. <https://doi.org/10.2478/jebbs-2025-0004>

ESG reporting incorporated into the corporate management strategies addresses the needs and expectations of a "relatively new user of this information", i.e. the investor community. Generally, the main benefits of incorporating ESG reporting into management strategies, as identified by the companies participating in the empirical research, include "a better corporate image, improved stakeholder relations, and improved internal communication" (Kobiela-Pionnier, 2023).

In practice, as the empirical research shows, the actions compliant with ESG requirements, meaning those not merely limiting themselves to complying with legal obligations, contribute to improved financial performance because they are better at managing risk, are more resilient to changes in the market environment, and also enjoy greater investor confidence; thus facilitating easier access to credit. From a broader perspective, "the integration of ESG factors is essential for the further development of modern capital markets, and sustainable investments that incorporate ESG pose a challenge for the entire financial sector" (Mikołajczyk, 2023). Corporate activities consistent with ESG principles are therefore one of the factors shaping a new paradigm for their market operations, based on communication using non-financial information of appropriate quality and credibility. Therefore, it is particularly important to emphasize that the low quality and credibility of information disclosed in ESG reports, primarily resulting from a lack of proper verification, ultimately results in a stakeholders' trust decline. Counteracting these threats requires effective implementation of ESG reporting standards and ensuring the appropriate quality of audit staff, i.e. equipped with "appropriate information, knowledge and tools, including specific guidelines prepared by the legislators" (Śledzik, Chmielewski, Płoska, Pęksyk, 2023).

The observations made so far, allow us to reasonably assume that, the actual corporate activities in the ESG areas, disclosed to the stakeholders in a reliable and credible manner—that is, not exceeding compliance with a legal obligation or intended to convince the stakeholders with unreliable information about the greenwashing characteristics—can bring extensive business benefits. Referring to the benefits that the companies can achieve through

such an approach to the ESG reporting in more detail, they can be defined as follows (Wyrwich-Płotka, 2024):

1. Improving a company's image and reputation – the perception of a company as socially and environmentally responsible increases stakeholder interest.
2. Strengthening market position – introducing sustainable products and services increases competitiveness.
3. Greater attractiveness to investors – improved access to financing.
4. Increasing innovation – stimulating development and the search for new solutions.
5. Increasing efficiency – process optimization, cost reduction.
6. Increased employee loyalty – awareness of the company's operations increases engagement.
7. Reducing regulatory risk by limiting the impact of legal changes.
8. Access to new markets – a response to the growing consumer preferences.
9. Reducing investment costs through the possibility of obtaining better financing terms and access to the so-called green finance.

Similar benefits from incorporating the ESG reporting into strategy were identified in a research conducted among Polish companies by Logos. The findings concluded that "companies that incorporate sustainable development goals into their strategy have the opportunity to expand into new markets, build a strong and credible brand, manage their company transparently, and increase employees' satisfaction" (Logos Research, 2023). The grounds for this approach is primarily the fundamental shift in consumer behavior and investor attitudes toward the principle of sustainable development. Over half of consumers are guided by the sustainable nature of products and services in their purchasing decisions. Investors, in turn, are predominantly guided by a positive ESG rating in their investment decisions, allowing companies perceived positively from this perspective to "benefit from better image." However, literal compliance with legal requirements alone is not a source of benefits in itself. Opportunities in this regard only emerge when legal content translates into real ESG actions, incorporated into strategic plans and daily managerial practices.

It should be noted, however, that the growing importance of ESG as a previously unheard-of form of non-financial reporting and the empirically proven business benefits resulting from it do not mean that companies have completely abandoned the traditional approach to business operations, i.e., focusing on sales and profits, ignoring environmental issues. This may stem from the assessment that rates of return on ESG investments are no higher than in the "classic paradigm". At the same time, however, it may also be a consequence of underestimating the fact that entities managing ESG factors are better perceived by the market, which also translates into tangible business benefits (Ślażyńska-Kluczek, Brzezek, 2024). Expanding knowledge and awareness in this area may therefore be a decisive factor in the dissemination of ESG, not only because of the legal obligation, which will inevitably never apply to all entities operating in the market, but primarily because of the business benefits ESG reporting brings.

In conclusion, it should be emphasized that companies applying ESG reporting, regardless of whether they are legally obligated, as in EU member states, including Poland, or disclose such content voluntarily, can derive the benefits described in the literature only when they incorporate ESG reporting into their current and strategic management practices, and when disclosing this information is considered an important factor in increasing development benefits and development potential.

3. The research problem

The above observations justify the conclusion that the legal obligation to the ESG reporting alone does not fully explain the phenomenon of its growing importance in the last decade. Real, long-term business benefits for companies can be observed when the ESG reporting is integrated into the corporate management process, and the disclosed information supports the economic efficiency and development potential of the organization (Freeman, 1984; Deloitte, 2023). The existence of a positive correlation between ESG reporting, confirmed by real-world actions, and business and development benefits for companies has also been confirmed in empirical research, both foreign and Polish.

The Polish context of integrating the ESG reporting into the management process is less recognized. The following research gap has been identified in this area:

There is a lack of sufficient scientific knowledge regarding the course and determinants of the strategic ESG integration process in Poland, viewed from a managerial perspective. Existing knowledge in this area should be enriched with the perspectives of those directly responsible for the corporate management processes regarding the benefits, but also the limitations, of integrating the ESG reporting into the ongoing and strategic management.

4. Research objective and questions

Due to the research gap identified above, the primary objective was to: Examine how managers in Poland perceive the process of integrating ESG into the business model.

In order to achieve the objective pursued, empirical studies have been carried out which have provided the necessary material to answer the following research questions:

1. What are the key motivations for integrating ESG strategies into a company's business model?
2. How does integrating ESG strategies impact the business model and perceived competitive advantage?
3. What are the greatest barriers and challenges to the process of strategic ESG integration?

In summary, the research objective and questions defined in this section provide a coherent analytical framework for examining ESG integration from a managerial perspective. By focusing on managers' motivations, perceived impacts on the business model and competitive advantage, as well as the key barriers and challenges associated with strategic ESG integration, the study addresses an important research gap in the Polish context. The formulation of the research questions reflects the exploratory nature of the study and directly informs the choice of a mixed-methods research design, which enables a comprehensive analysis of both quantitative trends and qualitative managerial insights. The subsequent methodological section outlines the research approach adopted to achieve these objectives and to ensure the validity and reliability of the findings.

5. Literature review

Three categories, viewed in their mutually reinforcing relationships and interdependencies, are key to the issues addressed here: ESG, business model, and strategic management. ESG has been previously addressed in the context of legal frameworks and management assumptions, referencing the key elements of this construct, which involve companies subject to legal requirements or those voluntarily complying with them disclosing non-financial data regarding the impact of their activities on the natural environment, social spheres, and corporate governance. The concept of ESG is generally derived from CSR, mentioned earlier in a different context, which also invoked the principle of sustainable development, permanently introducing responsibility for the ecological and social impacts of profit-maximizing business activities into the "classical" model of capitalism. The concept of CSR began to gain importance in the last decade of the last century, primarily in countries with the highest levels of economic development: the United States, Japan, and Western Europe. Its advocates argued that "maximizing corporate profits does not always lead to improved economic efficiency or overall prosperity, which is a consequence of market imperfections". They argued that the market mechanism contributes less to development and more to "environmental pollution and overexploitation of scarce resources", so the way to solve this issue "was to conduct responsible business – taking into account the well-being of various stakeholder groups" (Buczowski, Dorożyński, Kuna-Marszałek, Serwach, Wieloch, 2016). They attempted to demonstrate that the "classical market mechanism" means development at the price of irreversible loss of natural

resources for future generations, and that capitalism based solely on the profit maximization paradigm means current development at the expense of limiting future development opportunities.

The guiding principles for the CSR concept can already be found in one of the key management sciences, published in 1973, the work of P. Drucker: "Management: Tasks, Responsibilities, Practices", in which corporate responsibility was recognized as one of the main pillars of management. Corporate responsibility towards the stakeholders is a key principle underlying the CSR concept. Its essence can be considered "the organization's commitment to integrating social and environmental considerations into the decision-making process and taking responsibility for the impact of its decisions and activities on society and the environment" (Anuszkiewicz, Marona, 2012)". CSR can therefore be viewed as a conceptualization of responsible entrepreneurship, understood as the simultaneous entrepreneurial achievement of three sets of goals: economic, social, and ecological, while taking into account the needs of stakeholders" (Chodyński, 2013).

In the context of the above comments on CSR, it can be reasonably assumed that the ESG concept is a more advanced, although qualitatively different, form of CSR, as it defines all important areas of corporate responsibility (Morrison, 2021). E. Gemra et al., based on a review of the literature relating to the ESG concept, assumed that it refers to non-financial aspects of management, naming "a strategy, concept, draft, principles, standard, tool, pattern, system or model combining three types of management aspects: environmental, social, and governance, and encompassing interactions between them," i.e. factors "having a significant impact on the performance and value of entities, used in setting of the strategic goals of their activities in the environmental, social, and governance areas" (Gemra et al., 2024). These factors are intertwined and mutually condition each other, constituting the sustainable development paradigm. It serves as a fundamental point of reference for CSR and ESG, as corporate social responsibility, crucial to the former, has been clarified in ESG by distinguishing three aspects: environmental, social, and corporate, as equally coexisting in both theory and practice of the management (Łudzińska, 2024). The qualitative difference between CSR and ESG stems from the fact that "ESG dimensions are the criteria for assessing an organization's activities in the social, environmental and governance dimensions, while CSR activities are an organization's operating strategy within its chosen business model, which takes into account responsible management in the economic, social and environmental contexts" (Łudzińska, 2024). In light of the emerging trends in business management, this approach should be reflected in corporate management at both the operational and strategic levels. From this perspective, it is clear that ESG reporting should not be reduced to a legal requirement alone, but should be treated as an inherent component of a company's management model, a source of real resources generated by meeting stakeholders' needs and expectations, resources that allow for increasing the company's economic efficiency, and thus serve as a tool for strengthening its competitive

position. In practice, the lack of ESG reporting may mean that a company is deprived of some of the resources necessary to optimal achievement of its business goals.

The role of ESG, it's worth noting, will grow in the future not because of a legal requirement, but because of paradigmatic shifts in the approach to capitalism within the contemporary economics. This is the result of the evolving historical, socioeconomic, and political conditions over the past few decades, beginning in the 1990s, which have translated into a deterioration of the natural environment. All this has brought a qualitative shift in the axiology and teleology of business activity. Consequently, the economics has developed research on reducing financial risks and maintaining a balance between the economic, social, and ecological needs. Furthermore, there is a desire to simultaneously maximize profits and socio-environmental utility. These ideas have found a particular application in the concepts of green economics, the economics of moderation, and, in particular, the economics of sustainable development (Kubala, 2023). The result of these transformations in the economics doctrine has been the inclusion of the category of responsibility for the consequences of corporate actions aimed at sales and profit multiplication into the business paradigm. In the case of socially responsible business, therefore, the company is responsible not only for increasing the value of shareholders' shares – as is the case, as mentioned earlier in a different context, in a traditional business model – but also for meeting the needs and expectations of stakeholders. A management approach to ESG reporting means incorporating the category of responsibility for the areas identified in this concept into the business model adopted by the company.

Table 2.

Business model – selected definitional approaches

Author	Definition	Year
A. Osterwalder	A conceptual tool containing a set of elements and the relationships between them, expressing the philosophy of the company, a description of the value it offers to its customers, as well as the architecture and network of partners in creating and introducing significant values to the market and in generating both economically effective and sustainable revenue streams.	2005
D.J. Teece	A conceptual tool that describes the ways and mechanisms by which a company creates, delivers and captures value, and characterizes its core businesses from a value creation perspective.	2010
B. Wyrzykowska	A multi-component conceptual object that describes the way a business is run and the logic behind how a given enterprise creates value for its stakeholders and retains the most important stakeholders. It encompasses a several to a dozen or so business model components, selected on the basis of pre-defined criteria and consistent with the pre-established logics.	2020

Source: prepared based on: Olofsson, Farr, 2006, pp. 6-7; Morris, Schindehutte, Allen, 2005, pp. 726-735. Teece, pp. 172-194; Wyrzykowska, 2020, pp. 17-21.

The above review demonstrates the difficulty of defining a business model in a formula that could be accepted as generally applicable. The only practical common element among these definitions is that a business model, composed of many mutually interacting elements, is a conceptualization of an enterprise's strategy focused on the values important to the

stakeholders. The model includes elements such as the architecture of the mechanisms used to create, deliver, and capture the value that is important to the customer without compromising the enterprise's business objective (Ślażyńska-Kluczek, Brzezek, 2024). The differences concern the individual elements of a business model, the criteria for their selection, and their role in defining the methods of acquiring, creating, and retaining value. Based on an analysis of 30 business model definitions, M. Morris et al. identified three basic types (Morris, Schindehutte, Allen, 2005):

- financial – defining how a company generates profits,
- operational – the main emphasis is on internal processes,
- strategic – defining how a company is positioned on the market, the forms and areas of cooperation with business partners, and the directions of development.

Each of these definitions addresses the issue of value in a different way. Based on this, it can be assumed that ESG reporting can only be a component of a strategic model, and therefore fall under the purview of a strategic management. The ESG areas represent a value for the stakeholders: investors and customers. Their creation is linked to the protection and strengthening of universally recognized values, such as the protection of natural resources, respect for human rights, labor rights, and a democratic social order. These values are reinforced legally and institutionally, but also through internal mechanisms such as corporate governance. They are not a separate segment within the business model, but complementary to the fundamental, unchanging goal of a company's operations: profit maximization, understood as the multiplication of the shareholders' assets. The values fulfilled through a company's non-financial activities are one of the levers for optimizing the process of achieving its primary business objective. For these reasons, contemporary business models are strategically focused on capturing, creating, and maintaining value, giving it a conceptual rather than a financial character (Teece, 2010). From the perspective of the issue under consideration, the strategic management is more important. In an encyclopedic approach, i.e., generalizing the positions found in the literature, strategic management is defined as the process of evaluating, planning, and implementing a company's plans aimed at maintaining and/or strengthening its competitive advantage in the future (Sammot-Bonnici, 2014). The process in question is „information and decision-making” and concerns, unlike tactical and operational management, a long time horizon (actions and decisions) and a material horizon (the entire organizational process to which the management process applies) (Kałkowska, Pawłowski, Trzcielińska, Trzcieliński, Włodarkiewicz-Klimek, 2010). An essential distinctive feature of strategic management is its focus on the future. It concerns choices, i.e. what the organization will do and what it will not do to achieve specific goals and tasks that lead to the implementation of a specific mission and vision, „and ensuring a competitive advantage” (Morris Hodges, 2023).

Strategic management, understood as a process, encompasses four basic stages (phases) (Sammut-Bonnici, 2014):

1. Strategic assessment.
2. Strategic action planning.
3. Strategic action implementation.
4. Strategic action outcomes.

Diverse business objectives, such as market sector and industry diversity, mean that while the general objectives and structure of the strategic management process are common to all companies using this management model, specific applications differ due to sectoral, industry, and sometimes geographic specificities. Effective strategy implementation, which is a measure of the effectiveness of strategic management by management, also requires objectives that are aligned with the company's vision and mission. The literature describes two fundamental perspectives for strategy implementation, adopted at the planning stage (Sammut-Bonnici, 2014):

- The internal resources-based approach is appropriate for companies possessing unique internal resources, which are a potential source of long-term strategic advantage. This possibility increases the more unique these resources are, the more difficult it is to replace them with full-value substitutes.
- The external environment-based approach is based on the assessment that the source of long-term competitive advantage lies in the characteristics of the external environment, identified during the planning stage. A company guided by this approach should strive to operate in environments that provide the best conditions for building competitive advantage and profitability based on favorable environmental characteristics.

ESG reporting's use in strategic management is most natural from the latter perspective. The values important to stakeholders, like themselves, are part of the company's environment. Effectively generating and communicating these values in the environmental and social spheres becomes an instrument for building not only the image of a responsible organization but also for building a sustainable competitive advantage based on socially acceptable non-financial activities. No company, even one pursuing a strategy based on internal resources, operates in a social, legal, institutional, or technological vacuum. These interdependencies are illustrated in Figure 1.

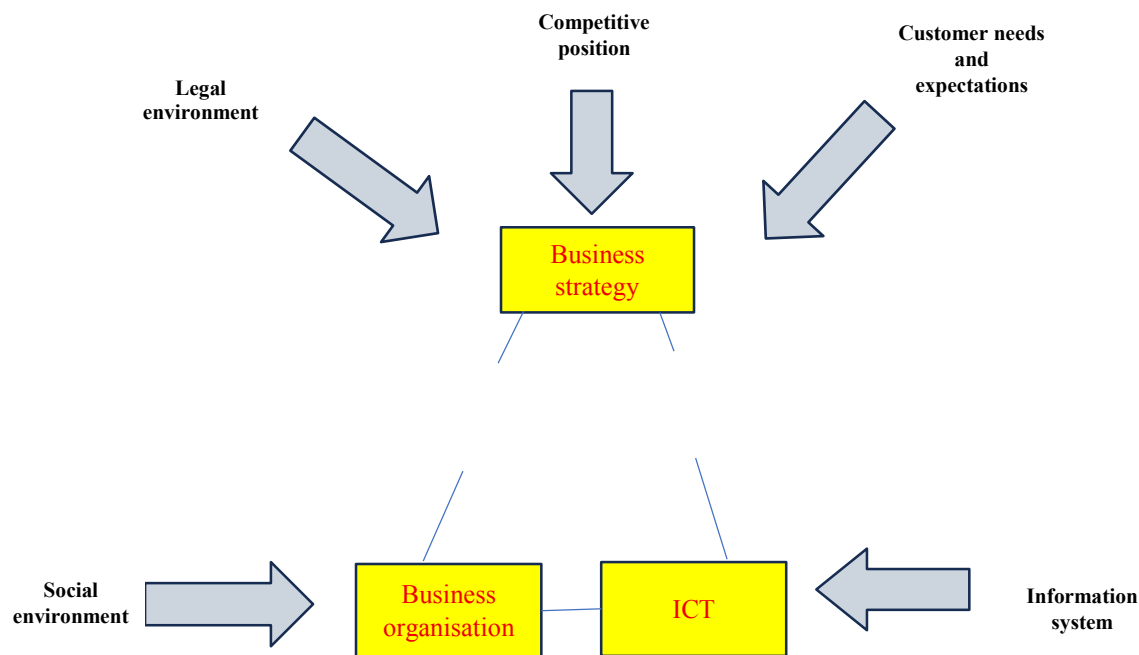


Figure 1. Business model vs. business strategy, processes, and information system according to A. Osterwalder.

Source: prepared based on: Olofsson, Farr, 2006, p. 7.

Each business model is implemented within a specific strategy by a specific business organization, whose actions are limited by the requirements of the social environment and the information system to which it actually has access. The framework of the strategy itself is determined by the legal environment, customer needs, expectations, and competitive position (current and planned). ESG values are a component of customer needs and expectations, shaped by the legal environment and social pressures. In this situation, ESG reporting for companies cannot be considered merely a matter of legal requirements, which – as mentioned elsewhere – will never apply to all categories – but rather a necessary component of strategic management.

5.1. Integrating ESG strategies with the enterprise's business model using stakeholder theory

Stakeholder theory, systematically developed by R. Edward Freeman (1984), expanded management thinking beyond shareholders to include all groups affected by organizational decisions (Freeman et al., 2010; Mainardes, Alves, Raposo, 2011). Originating from the Stanford Research Institute's 1963 concept, the term "stakeholder" denotes entities essential to an organization's existence. Freeman defined stakeholders as any individuals or groups who can influence or are influenced by organizational goals—a view later refined through classifications of internal and external stakeholders (Stoner, Freeman, Gilbert, 1997) and the notion of "strategic fans" (Obłój, 2007). Freeman argued for shifting corporate responsibility from general social responsibility to stakeholder accountability, integrating ethical and

economic perspectives within strategic management. This marked a paradigm shift toward transparency, governance, and ethical value creation (Freeman et al., 2010; Mainardes et al., 2011). The stakeholder framework also underlies the concept of the *social license to operate*—stakeholder acceptance of corporate activities—now a key determinant of sustainable business. Growing social awareness and stakeholder activism make such acceptance critical, as its absence can hinder or block business initiatives (Boutillier, 2024; Zdziarski, 2017). In light of the above, ESG reporting is consistent with stakeholder theory, as it contributes to the value creation required by this concept for all stakeholder groups (customers, employees, suppliers, communities, investors), not just shareholders. The impact of business activities is not transferred to stakeholders but is instead considered and respected in the strategic management process. Strategic management that incorporates ESG reporting is therefore key to long-term success and sustainable development.

One of the benefits is gaining a competitive advantage. The mechanism for building it based on ESG assets can be explained in terms of resource-based theory (RBV). Currently, the dominant approach is that "achieving competitive advantage depends on the course of action and response to changing conditions", and thus, achieving competitive advantage involves identifying sources of competitive advantage that ensure the creation of value that provides it" (Wernerfelt, 1984). For companies operating currently, i.e., in accordance with this latter paradigm, a source of competitive advantage may be the properly managed disclosure of data from specific ESG areas, in line with stakeholder needs and expectations. Proper strategic management of this type of non-financial reporting can serve as a resource that allows stakeholders to offer unique value compared to the competition. The key theoretical framework that can explain the operation of this mechanism is resource-based theory, which generally assumes that the source of a company's competitive advantage lies not in its products or services, but in its unique internal resources, upon which companies should build their strategies to capitalize. The shift towards this approach was initiated by B. Wernerfelt, who considered resources to be the primary focus of strategic management leading to competitive advantage (Wernerfelt, 1984). The premises for this approach existed in economic theory before. The role of diverse resources in enhancing economic performance and competitive advantage was recognized by E.H. Chamberlin and later developed by E. Penrose, who emphasized the link between an enterprise's growth and its effective use of resources (Ujwary-Gil, 2009). B. Wernerfelt defined resources as assets semi-permanently tied to a company, while H. Itami distinguished physical, human, financial, and "invisible" resources such as skills, technology, and trust. D.J. Teece differentiated between *resources*—inputs like information or capital—and *capabilities*, the outcomes of their strategic interactions. As Ziolkowska (2012) notes, resources include all tangible and intangible assets, rights, and knowledge that can support enterprises' development. Viewed statically, they represent existing assets; dynamically, they become drivers of growth only when strategically utilized within the management processes.

It is therefore worth emphasizing that ESG reporting does not generate business benefits for the company on its own and does not provide it with a competitive advantage as a *deus ex machina*, but when properly managed and taken into account in the company's strategy, it provides the company with the usefulness to achieve these goals.

The introduction of the WIG-ESG index by the Warsaw Stock Exchange, supporting the green transformation, may contribute to answering the question about the state of awareness of Polish businesses on this issue, as well as the question about the potential use of ESG reporting as a pro-development and pro-competitive resource. The literature has viewed this initiative in terms of benefits for companies "from building a positive image, acquiring motivated and qualified staff, better supplier relations, and lower cost of capital" by companies incorporating socially responsible policies in areas defined by ESG into their strategic management (Trzcińska, 2024). However, due to the lack of engagement of individual investors in ESG issues, a key indicator of which was the results of the 2023 Polish National Investor Survey, which showed that as many as 80% of respondents did not consider ESG factors when making investment decisions, the publication of the WIG-ESG index (Investor Zone, 2025) was discontinued on June 28, 2024. It should be emphasized that the example of the WIG-ESG index cited in this article serves as institutional context and does not constitute a direct conclusion from the empirical research conducted, which focuses on the declarative assessments and experiences of managers.

This suggests that strategic management consistent with ESG is not widely practiced in Poland. This means that ESG is not an internal resource used on an excessive scale to build competitive advantage. It is therefore all the more important to identify the trends occurring in this area in Polish business environments and their underlying causes.

5.2. ESG implementation research review

The link between ESG-compliant strategic management and economic performance, innovation, image benefits, and achieving a competitive advantage is supported by empirical research from both Polish and international studies. One of the first studies in Poland was conducted at the beginning of the previous decade as part of the "ESG Analysis of Companies in Poland" project, with the aim of answering the question about the reasons for the low level of ESG reporting. This research revealed a low level of interest in ESG data reporting among Polish investors, a low awareness of the impact of non-financial data on company value, as well as a lack of reporting skills, and consequently a low level of ESG reporting. However, this research also revealed evidence of high dynamics in the responsible investment market in Europe. The conclusions of this study recommended taking two-pronged actions: on the one hand, to raise investors' awareness of the social importance of responsible business behavior, and on the other – to improve the quality of ESG data reporting (Sroka, 2012).

Based on the discontinuation of WIG-ESG publication earlier in a different context, it appears that the reasons identified in the cited study are still highly valid. This situation does not foster increased interest in ESG-compliant strategic management in Polish enterprises. This may be due in particular to the controversies in the Polish green bonds market related to investing in the coal and renewable energy subsectors, although research findings in this area are not considered fully reliable. The impact of ownership is evident in the significant impact of ESG metrics on stock price returns. Individual investors playing a significant role can affect the way stock prices react to changes in ESG metrics (Chodnicka-Jaworska, 2025). Based on this, it can be concluded that potential issuers of green bonds are not sufficiently prepared to take advantage of the greenium, i.e., a kind of premium in the form of reduced costs and access to cheaper loans obtained from investing in environmentally friendly projects at the expense of lower investment profitability. This situation differs significantly from other EU countries, where "green bonds" issued by credible companies are traded at a statistically and economically significant greenium. This situation is changing, however, with the increase in returns on green bond investments stemming solely from concerns about climate change, not from the attitudes of companies themselves (Chodnicka-Jaworska, 2025). In Poland, the situation on the green bonds market seems to be the opposite, which does not favor treating ESG data as a significant resource in creating business benefits and building a competitive advantage.

A somewhat different approach to ESG data as an indicator of corporate sustainability policies emerges from empirical research on the consumer side. Although consumers still consider price and product appearance when shopping, nearly half of respondents, despite their lack of interest in ESG data, believed that implementing sustainability principles offers companies an opportunity to achieve better financial results. According to a 2021 Pricewaterhouse Coopers report, consumers and employees expect companies to consider sustainability in their investment decisions. In these studies, they declared that they were more likely to purchase or work for companies that implemented ESG factors (Ślazińska-Kluczek, Brzezek, 2023).

D. Ślazińska-Kluczek and M. Brzezek obtained empirical data in their own research indicating the following benefits obtained by enterprises from implementing ESG factors in the management process:

1. the image of a less risky entity for investors,
2. obtaining capital at lower costs, which increases the entity's resilience to crises, the ability to meet changing market demands and build a competitive position,
3. reducing risk in relation to social costs and environmental responsibility,
4. the image of a more attractive entity as a place of potential employment,
5. improvement of competitiveness, resulting from the customers' expectation that entities implementing ESG factors are more capable than others of taking real, and not only image-related, actions to protect and improve the climate, which results from the fact that the number of consumers interested in climate protection issues is increasing (Ślazińska-Kluczek, Brzezek, 2023).

In the light of the results of empirical research analyzed by D. Ślażyńska-Kluczek and M. Brzezek, ESG reporting generates the following phenomena in the area of processes beneficial for enterprises that apply it:

1. entities with a high CSR rating (ESG factors management assessment) have access to cheaper capital,
2. a trend towards a systematic increase in the impact of sustainable development factors on management decisions and strategic planning of enterprises,
3. increased resilience to crises of enterprises operating in accordance with the principle of sustainable development and incorporating ESG factors in their management, due to their increased ability to meet market demands and build a strong competitive position,
4. better understanding of the actual capabilities and needs of the enterprise thanks to ESG reporting, translating into better operational and strategic decisions,
5. reduction of enterprise risk related to social costs and environmental responsibility,
6. the occurrence of a positive correlation between sustainable operations and taking into account ESG factors in management and customer loyalty (which is particularly visible in the case of generation Y (growing up in times of political transformation and dynamic development of digital technologies),
7. increased attractiveness of environmentally friendly enterprises on the labor market,
8. a qualitative change in the expectations of consumers and other stakeholder groups who expect enterprises to be responsible for the effects of their actions on the environment and to transparently inform about these effects (in the light of SEC Negative research in 2023, more than 2/3 of consumers expect such information, and a similar percentage expects this information to be disclosed in a consistent and understandable manner) (Ślażyńska-Kluczek, Brzezek, 2023).

In the context of the above-mentioned empirical material, the observation by D. Ślażyńska-Kluczek and M. Brzezek can be considered accurate in its entirety that "the costs incurred by an entity for sustainable development, i.e. expenditures on environmental and social goals, or establishing and complying with corporate governance, will be balanced in the long term by a lower cost of acquiring capital, will facilitate its acquisition and maintenance, and will also contribute to a better perception of the entity by customers and potential employees" (Ślażyńska-Kluczek, Brzezek, 2023). The costs in question can therefore be considered a form of investment, discounted through access to cheaper capital and improved image in the eyes of other participants and various stakeholders, which ultimately translates into improved financial results and a strengthened competitive position. From this perspective, the management aspect of ESG can be defined as a lever for optimizing decisions at both the operational and strategic levels.

P. Chodnicka-Jaworska's research yields similar conclusions. ESG-compliant management is indirectly related to these conclusions because they demonstrate its effects through investor reactions. According to the cited researcher, using ESG metrics can improve models that

measure credit risk and default probability, which can lead to more effective risk management and higher investment returns from their perspective. However, she also notes that "most financial institutions are in the process of redesigning their credit and default risk assessment methods", and therefore their current responses to ESG reporting are not yet fully developed. Nevertheless, 1) ESG ratings significantly reduce stock price volatility and contribute to higher growth rates; 2) significantly influence interest capitalization, taking into account regional, sectoral, and economic conditions; 3) significantly influence energy sector investment returns and stock market capitalization, taking into account political divisions, business cycle phases, and ownership forms; 4) green bonds have higher rates of return than conventional bonds, which depend on economic and geographic factors (Chodnicka-Jaworska, 2025). These data may be a signal to company managers that strategic management consistent with ESG is increasingly better perceived by investors and may thus generate benefits for these companies, mainly in terms of access to cheaper credit.

The relationship between company's ESG performance and size was investigated by L. Bohdanowicz and M. Aluchna. Large companies are significantly more likely than smaller ones to consider ESG activities to enhance their reputation and to ensure accurate reporting, as they want to avoid suspicions of environmental and social abuse, which, according to stakeholders, they are more likely to engage in. In this way, they seek to increase their influence on the stakeholders they want to influence. Large companies are also aware of the expectations that they will become leaders in implementing ESG activities and thus serve as role models for smaller entities. Such processes are also observed in companies with increasing foreign shareholding. According to the cited researchers, "this may result from transferring higher standards from the home country, but also from a greater desire for social acceptance on the part of such an owner in the new institutional environment, and thus, a desire for companies with foreign shareholding to be perceived as pro-social and pro-environmental". In these new conditions, through ESG achievements and reporting on them, a foreign investor can legitimize its investments in the host country and send positive signals to local stakeholders about them, striving to gain favor" (Bohdanowicz, Aluchna, 2023). Regardless of the intentions of foreign investors, their activities in ESG-defined areas serve as a model for enterprises with a majority of Polish capital in this respect and an incentive for their development. Because in Polish conditions, as can be inferred from the empirical data cited, public awareness of the importance of ESG for enhancing enterprise value, improving economic performance, and increasing competitive advantage is relatively low. Therefore, there is also little interest in using ESG reporting in strategic management as an internal resource, generating the formerly mentioned benefits. This is a separate issue, however, and is largely unfavorable for political considerations, as the controversy surrounding the direction of the energy transition is largely political, i.e., whether it should be based on fossil fuels—which is contrary to ESG assumptions—or on renewable sources—which is consistent with them. This factor objectively lowers the importance of ESG reporting and the attitude towards the legal

obligations established at the level of EU law and implemented into the national legal system. The issue of benefits from ESG-compliant management is much clearer in the results of foreign research. For example, the results of research conducted in Singapore, Saudi Arabia, and South Korea will be cited, where there is no legal obligation regarding non-financial reporting, but they are used voluntarily by enterprises.

Saudi research focused on the relationship between ESG reporting and the widely comprehended effectiveness of enterprises operating in this country. N.H. Ab Aziz and S.M. Alshdaifat, referring to the results of their own research conducted among enterprises in Singapore and an extensive literature review, state that the impact of ESG reporting on enterprise performance is multidimensional and covers financial aspects, market valuation, environmental, social, and corporate governance. This is supported by the literature, which provides much empirical evidence of a positive correlation between ESG reporting and corporate performance, especially financial performance. ESG reporting also plays a key role in promoting greater transparency, accountability, and corporate social responsibility, thus contributing to social development, stakeholder engagement, and ethical business practices. ESG also has a positive impact on the environment, as it contributes to raising public awareness of the need for environmental practices in corporate operations. This also applies to the social sphere, where understanding and acceptance of sustainable practices by companies is growing. In terms of corporate governance, ESG reporting has a significant positive impact on management, which positively impacts the company's value for stakeholders, especially investors but also consumers (Ab Aziz, Alshdaifat, 2024). In turn, research by N.B.M. Ali et al. on Saudi companies showed a positive correlation between ESG reporting and corporate profitability, which – according to the authors of the cited studies – confirms the validity of the assumptions of stakeholder theory, according to which companies strongly committed to ESG issues enjoy greater investor trust than others and are able to improve risk management and increase organizational efficiency. The results also confirm the assumption that disclosure and transparency of information about sustainable development practices are key factors in improving corporate profitability, as institutional investors prioritize companies that implement ethical business practices, sound corporate governance principles, and environmental responsibility. For consumers, disclosure and transparency of ESG practices translate into informed purchasing decisions aligned with their values, with sustainability becoming an increasingly preferred value among social stakeholders. This is particularly true for industries where environmental and social impacts play a key role in consumer choices. Generally, in the Saudi reality, the disclosure of ESG information is becoming a fundamental point of reference for assessing its quality, which, after positive verification by stakeholders, is a source of significant business and development benefits for companies that disclose this type of information reliably (Ali et al., 2025).

Similar benefits of ESG reporting for companies are indicated by the results of Korean research. The research was conducted between 2021 and 2023 on a group of 8,478 South Korean companies listed on the stock exchange. It showed that:

1. there is a positive correlation between these companies' achievements in ESG areas and the level of innovation, which is even stronger in crisis situations (the COVID-19 pandemic was the reference point);
2. corporate innovation resulting from ESG activities increases stakeholder engagement and dynamizes the process of creating networks of relationships that facilitate knowledge exchange, resource sharing, and joint problem-solving;
3. actions taken in ESG areas, regardless of whether they result from a legal obligation or are undertaken voluntarily, are a source of competitive advantage;
4. ESG activities undertaken by companies foster stakeholder collaboration and provide companies with key resources and networks, thus creating an environment conducive to innovation;
5. implementing ESG-compliant strategic management is beneficial for companies as it increases their innovation potential and ensures greater competitive resilience (Lee, 2025).

The above-mentioned foreign research results cannot be symmetrically related to Polish conditions, because, as noted in the conclusion of Korean research, ESG policy, stakeholder expectations, and institutional structures differ significantly in individual countries, and the relationship between ESG and innovation may manifest itself differently in other regions (Lee, 2025). However, they can provide a reference point for examining the relationship between ESG activities undertaken by Polish enterprises and the development and competitive benefits achieved as a result. This requires taking into account the delays and limitations that occur in the implementation of ESG in Polish conditions, as mentioned earlier.

6. Research Methodology

The study employed a mixed-methods approach, combining quantitative and qualitative techniques. The results were derived from the application of method triangulation allowing for increased credibility and a more comprehensive understanding of the phenomenon being analyzed. This approach involved quantitative and qualitative research using the following methods:

- a) Quantitative research was conducted using a dedicated survey questionnaire developed specifically for this project, designed in Google Forms. The results were used to identify trends in ESG practices and reporting among Polish companies, as well as the perception of this issue within this environment. The questionnaire consisted of four sections:

- demographic and company data,
- ESG integration into the business model,
- impact of ESG integration,
- barriers and challenges.

The sampling was purposive, and respondents included board members, directors/managers, and specialists employed in companies across various industries (construction/real estate, manufacturing, services, energy, finance, and agriculture). Respondents were recruited through the author's professional network, gathered via LinkedIn, using snowball sampling, where invited participants could recommend additional individuals to participate in the study. This approach is justified in studies where the target population may be difficult to access or dispersed. Professional networks (e.g., LinkedIn) enable effective recruitment of individuals with desired professional profiles (Dusek, Yurova, Ruppel, 2015; Ting, Memon, Ramayah, Cheah, 2025; Heckathorn, 2011). A total of 28 individuals participated in the study.

- b) The second stage of the research was qualitative and involved conducting five in-depth individual interviews (IDIs) with managers responsible for implementing ESG strategies in their organizations. The qualitative findings were used to outline the broader research context, understand the mechanisms of the relationship between ESG activities and the benefits achieved by companies, and identify potential future development scenarios in Poland. Respondents were selected purposively based on three criteria:

- managerial position,
- experience in ESG implementation, and
- representation of different industries to ensure a diversity of perspectives.

Participants were recruited through the author's professional network. Each respondent was informed about the study's purpose and assured of its voluntary and anonymous nature. The interview scenario included 17 open-ended questions addressing topics such as ESG integration into corporate mission and strategy, organizational and cultural barriers, and ESG-related priorities and objectives. Interviews were recorded in the form of detailed author's notes and analyzed using content analysis to identify recurring themes, categories, and patterns that illustrate key mechanisms of ESG integration into management processes.

The adoption of a mixed-methods design enabled the triangulation of data sources, combining survey findings with insights derived from qualitative interviews. This approach allowed for both the validation of general trends and a deeper exploration of managerial perspectives and processes related to the integration of ESG into business models.

7. Research Results

7.1. Results of the quantitative survey

The quantitative survey was conducted among 28 respondents representing various industries and management levels within organizations operating in Poland. Men accounted for 60.7% of the sample, while women represented 39.3%. Figure 2 shows the gender.

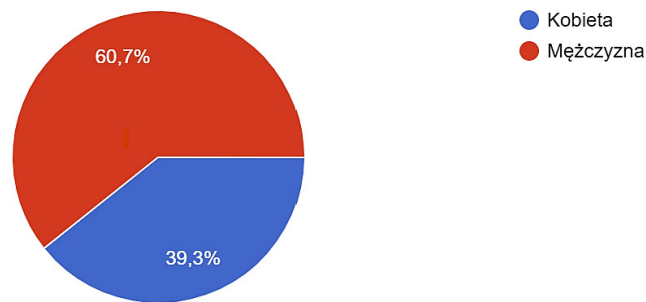


Figure 2. Gender (legend in Polish).

Source: author's own study.

The largest group of participants came from the construction and real estate sectors (32.1%), followed by the financial and service sectors (17.9% each). Figure 3 shows the industry.

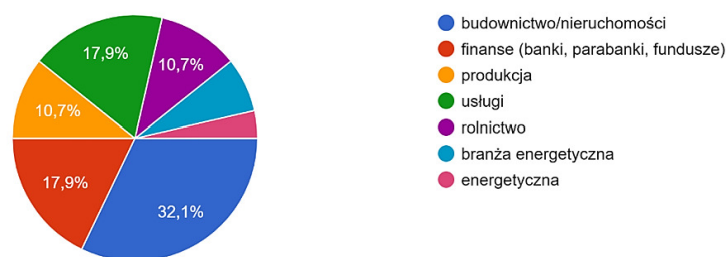


Figure 3. Industry (legend in Polish).

Source: author's own study.

Respondents were primarily employed in large and medium-sized enterprises (39.3% each), while micro and small enterprises constituted 21.4% of the sample. Figure 4 shows size of employment.

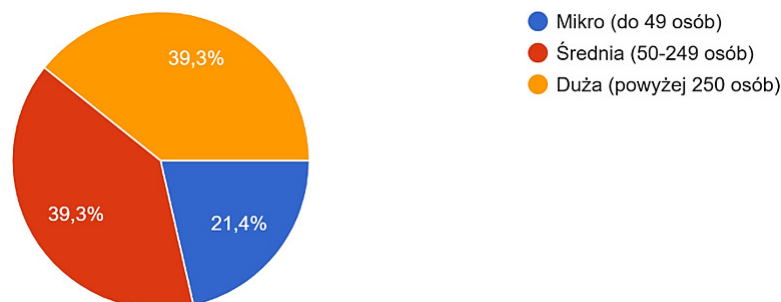


Figure 4. Size of employment (legend in Polish).

Source: author's own study.

In terms of organizational roles, directors and board members represented the majority (60.7%), followed by managers (28.6%) and specialists (10.7%). Figure 5 shows position in the organizational hierarchy

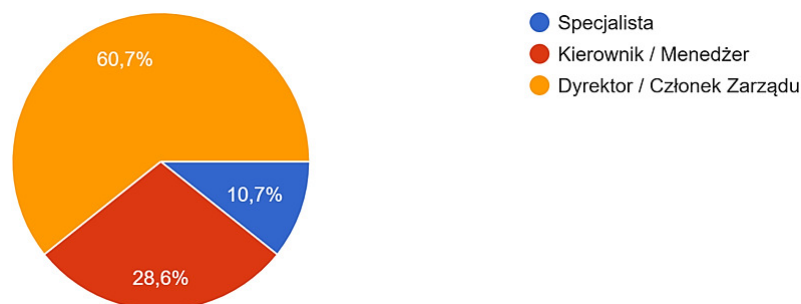


Figure 5. Position in the organizational hierarchy (legend in Polish).

Source: author's own study.

Most respondents reported partial or full integration of ESG principles into their organizations business models. ESG objectives are increasingly being embedded in corporate missions and visions, indicating that ESG activities are becoming an integral part of development strategies rather than serving solely as branding instruments. However, limited funding for ESG projects and the absence of regular reporting suggest that implementation remains at an early stage in many organizations. Figure 6 shows ESG integration into the business model and present survey results expressed as percentages of respondents across a five-point Likert scale.

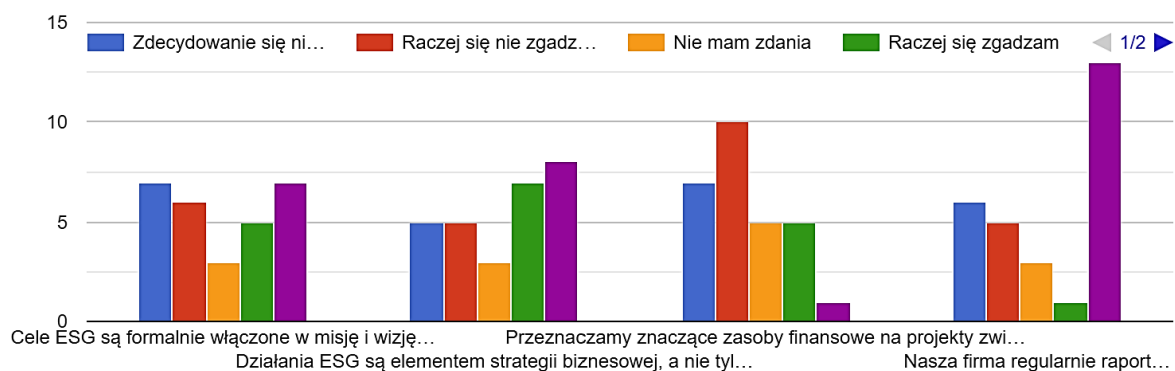


Figure 6. ESG integration into the business model (legend in Polish).

Source: author's own study.

Respondents identified reputation and corporate image as the areas most positively influenced by ESG integration, followed by customer loyalty. The perceived impact on financial performance and talent acquisition was moderate, likely due to the long-term nature of ESG initiatives. Figure 7 shows the impact of ESG integration. ESG integration into the business model present survey results expressed as percentages of respondents across a five-point Likert scale.

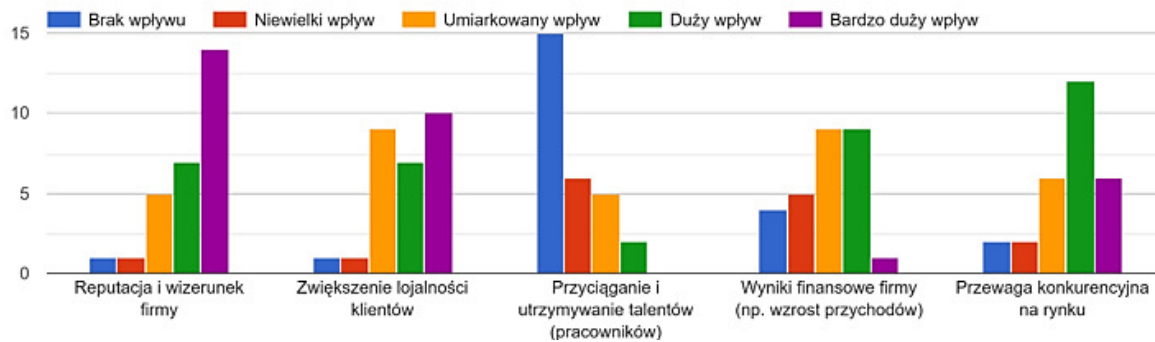


Figure 7. The impact of ESG integration. ESG integration into the business model (legend in Polish).

Source: author's own study.

A majority of respondents agreed that ESG integration contributes to building competitive advantage. The most frequently cited barriers to ESG implementation included:

- Lack of transparent legal regulations (92,9%).
- Insufficient internal competencies (75%).
- Low employee engagement (67.9%).
- Limited financial resources (60.7%).

Figure 8 shows barriers and challenges.

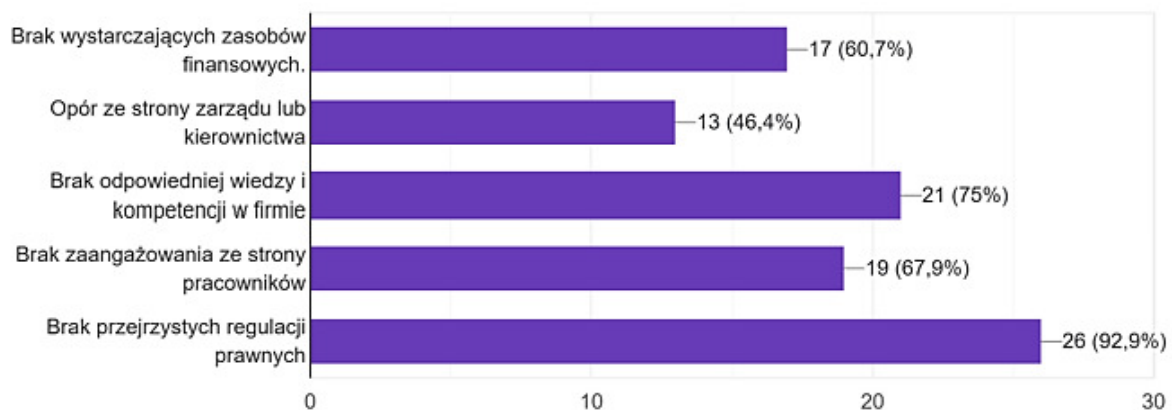


Figure 8. Barriers and challenges (legend in Polish).

Source: author's own study.

7.2. Results of the qualitative study (IDI)

The qualitative stage comprised five in-depth individual interviews (IDIs) with managers representing diverse economic sectors—real estate, finance, services, energy, and manufacturing—conducted in line with the methodology outlined earlier. Across all analyzed industries, ESG implementation was found to be primarily strategic and economic, rather than reputational. Managers viewed ESG as a prerequisite for competitiveness, access to financing, and long-term business continuity, rather than as an image-driven initiative. The implementation process was described as a form of “forced evolution”, driven by

EU regulations, climate pressures, and growing customer expectations. ESG has thus transitioned from a declarative stage to a strategic and financial stage, directly shaping investment priorities and operational decisions. In every sector examined, ESG was found to reshape the core business model:

- In finance, it influences risk assessment and credit processes.
- In manufacturing, it drives the creation of low-emission product lines.
- In energy, it redefines the investment mix.
- In services, it becomes part of the advisory offering.

While ESG creates new revenue streams, it simultaneously necessitates higher investment levels and the development of new organizational competencies. Three main groups of implementation barriers were identified:

- Cultural- resistance to change and entrenched organizational practices.
- Economic – high initial capital expenditures (CAPEX).
- Competency-related – insufficient expertise in energy management, climate analysis, and ESG reporting.

Management plays a central role in integrating ESG objectives into incentive systems, decision-making structures, and investment processes. Supervisory boards primarily focus on reputational risk and regulatory compliance. ESG serves as a source of competitive advantage, although the mechanisms vary by industry:

- In capital-intensive sectors (energy, finance, real estate), the advantage arises through improved access to capital and risk reduction.
- In services and manufacturing, it stems from enhanced offerings and customer loyalty.

ESG now spans the entire value chain. Organizations increasingly adopt a “make strategically, buy tools” model, internalizing core ESG competencies while sourcing technical tools and reporting systems externally. Although ESG initiatives entail higher initial investments, these costs are offset over time by reduced operating expenses. New professional roles—such as climate risk analysts—are emerging within organizations. The ESG culture in Polish enterprises remains in the formative phase, with strong awareness at the managerial level but weaker operational engagement.

7.3. Integrated analysis of quantitative and qualitative results

The triangulation of quantitative and qualitative results provided a deeper understanding of how ESG strategies are implemented in organizations operating in Poland. The data clearly indicate that ESG is evolving beyond its image-building function, becoming an integral component of business models and organizational missions. Across both research phases, respondents emphasized that ESG implementation has a strategic and economic character, rather than being merely declarative. Quantitative and qualitative findings consistently revealed that ESG exerts the strongest influence on corporate reputation and customer loyalty, while its

financial impacts are indirect and long-term. Depending on the industry, ESG adoption enhances credibility, facilitates access to financing, and strengthens both reputational and relational advantages. At the same time, the results confirm the presence of numerous implementation barriers, with the most significant being limited financial resources and insufficient competencies in ESG measurement and reporting. The qualitative research deepened these insights by identifying three key categories of barriers—cultural, economic, and competency-related—and highlighted the crucial role of senior management in leading the implementation process. In summary, the triangulation of findings indicates that Polish enterprises are currently in a transitional phase, moving from declarative to strategic and operational ESG implementation.

8. Discussion of the Results, Study Limitations, and Recommendations for Further Research

8.1. Discussion of Results

The research findings indicate that the integration of ESG strategies into the business models of Polish enterprises remains at an early stage of development. Although awareness of the importance of sustainable development is steadily increasing, many managers continue to perceive ESG primarily as a regulatory requirement, rather than as a strategic management tool capable of generating added value for the organization and its stakeholders. Consequently, the potential of ESG as a driver of competitive advantage remains largely underutilised.

The results are consistent with previous research (Ślażyńska-Kluczek, Brzezek, 2023; Chodnicka-Jaworska, 2025), which highlights that the effective implementation of ESG principles can enhance corporate reputation, investor confidence, and access to external financing. However, the study also identifies significant barriers, particularly the lack of auditing competencies and low quality of ESG reporting, which hinder the full realization of ESG's potential as a management instrument.

When compared with international studies (e.g., Ab Aziz, Alshdaifat, 2024; Bohdanowicz, Aluchna, 2023), a distinct difference emerges: in countries with more mature capital markets, ESG is increasingly perceived as a source of innovation and strategic advantage, whereas in Poland, the dominant approach remains reactive and compliance-driven, focused on adapting to legal requirements rather than proactively integrating sustainability into core strategy. This divergence can be attributed to insufficient stakeholder pressure and the limited number of domestic examples of best practices in ESG implementation. The findings further suggest that the benefits of ESG integration are most evident among large enterprises and organizations with foreign capital participation, which tend to use non-financial reporting as a reputation-building and credibility-enhancing tool. In contrast, smaller enterprises continue to face

structural barriers related to limited resources, insufficient knowledge, and a lack of institutional support.

In summary, the effective integration of ESG into business models requires reinforcing both managerial education and organizational capabilities. ESG should be regarded not as a regulatory burden, but as a strategic resource that enhances innovation, strengthens organizational resilience, and supports the long-term sustainability and competitiveness of enterprises.

8.2. Study Limitations

Despite providing valuable insights, this study has several limitations. First, it is exploratory in nature and relies primarily on self-reported data from managers, which may introduce a declarative bias and reduce the objectivity of the findings. Second, the study focuses exclusively on organizations operating in Poland, which limits the comparability of results across different institutional and market contexts. Another limitation is the absence of in-depth quantitative analysis to assess the relationship between the degree of ESG integration and companies' financial and non-financial performance indicators. Furthermore, sectoral differences were not analyzed, despite evidence in the literature suggesting that industry-specific factors significantly influence the approach and pace of ESG adoption. The study also did not include a systematic evaluation of ESG report quality or their alignment with recognized reporting standards, which restricts the ability to assess the reliability and authenticity of the disclosed information. Consequently, it remains difficult to determine the extent to which implemented ESG practices reflect genuine strategic commitment versus symbolic or greenwashing behavior.

8.3. Recommendations for Further Research

To advance the understanding of ESG integration within corporate business models, further research should focus on several key areas. First, quantitative research using statistical and econometric methods should be developed to identify the relationships between ESG integration levels and organizational outcomes such as financial performance, reputational capital, and innovation capacity. Second, comparative analyses between Polish enterprises and those from other EU countries are recommended. Such studies would enable the assessment of organizational maturity, as well as differences in ESG implementation mechanisms arising from varying institutional and cultural contexts. Third, longitudinal studies would provide valuable insights into the evolution of managerial attitudes toward ESG and help capture long-term changes in the integration process. Additionally, future research should explore the role of management education and training in enhancing the effectiveness of sustainable development practices and their integration into corporate strategy.

In conclusion, the further development of research in these areas will contribute to a more comprehensive understanding of the mechanisms, conditions, and outcomes of ESG integration in business models. This, in turn, will enrich the knowledge base of sustainable management and support the practical implementation of ESG principles in Polish economic practice.

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IMPLEMENTATION OF AN E-COMMERCE SYSTEM AS A STRATEGIC INITIATIVE FOR THE DEVELOPMENT OF SMES IN THE DIGITAL ERA

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Purpose: This paper aims to investigate the implementation of e-commerce systems as a strategic initiative for SMEs development in the digital era. It seeks to identify the key drivers, challenges, and outcomes of such adoption, focusing specifically on the Polish market, to understand how e-commerce influences competitiveness, operational efficiency, and market expansion.

Design/methodology/approach: The study employs a pilot research approach, utilizing an online survey questionnaire distributed to 86 Polish SMEs. The methodology includes descriptive statistics, Spearman's rank correlation analysis, linear regression, and Chi-square. The research is grounded in a theoretical review of digital transformation and e-commerce strategy.

Findings: The research identifies competitive pressure and brand-building as primary drivers, which are simultaneously the most severe challenges. The choice of e-commerce model (marketplace, B2C, B2B) significantly moderates the type of competitive advantage achieved. Critically, strategic e-commerce adoption supports competing through customer experience, branding, and data use rather than price alone.

Research limitations/implications: The main limitations include a pilot-scale sample focused on Poland and an underrepresentation of micro-enterprises and owner perspectives. Future research should expand the geographical and sectoral scope and employ longitudinal designs to assess long-term strategic impact.

Practical implications: SMEs should carefully select an e-commerce model aligned with strategic goals and prepare for operational challenges (e.g., logistics, skills).

Originality/value: Demonstrates a strong link between implementation drivers and challenges and highlights the moderating role of e-commerce models in shaping SME competitive advantage, offering novel insights for both academics and practitioners in SME digital strategy.

Keywords: e-commerce; SME; digital; strategy; advantages; challenges.

Category of the paper: Research paper.

1. Introduction

The significance of this paper's topic stems from the growing role of SMEs in economic development and the increasing pressure they face to adapt to rapid digital transformation. Despite their importance, SMEs often face constraints such as limited resources, limited market access, and lower technological capabilities. E-commerce offers a strategic opportunity to overcome these barriers by expanding market reach, improving efficiency, and strengthening competitiveness. At the same time, its implementation presents significant challenges that require strategic planning and informed decision-making. Therefore, examining the adoption of e-commerce as a strategic development tool is both timely and relevant, as it helps explain how SMEs can enhance their long-term competitiveness and growth in the digital economy.

Undoubtedly, small and medium-sized enterprises play a key role in economic development, contributing to employment, innovation, and GDP growth. However, the digital era, characterized by widespread internet access, mobile technologies, and data-driven decision-making, offers SMEs new opportunities to overcome the barriers mentioned above. E-commerce systems enable enterprises to conduct commercial transactions electronically, integrating sales, marketing, customer service, and logistics through digital platforms. For SMEs, the implementation of e-commerce is no longer merely an operational decision but a strategic initiative that can determine long-term competitiveness and survival. Which is why the rapid development of digital technologies has significantly transformed the business environment, forcing small and medium-sized enterprises (SMEs) to adapt to new market conditions. Consequently, the implementation of e-commerce systems has become one of the key strategic initiatives supporting SME growth in the digital era.

This paper aims to examine e-commerce as a strategic tool to enhance competitiveness, expand market reach, and improve operational efficiency for SMEs. The research questions were formulated based on an analysis of the existing literature on e-commerce as a strategic instrument for SME development in the era of digitalization. The study discusses key benefits, challenges, and critical success factors related to e-commerce implementation. Given the above, the following research questions were posed: RQ1. What are the primary internal and external drivers motivating SMEs in Poland to adopt e-commerce, and how do these drivers differ from those of larger enterprises? RQ2. How do specific e-commerce implementation challenges (e.g., cybersecurity, logistics, digital skills gap) mediate the relationship between e-commerce adoption and the achievement of strategic goals like market expansion? RQ3. How does the e-commerce model (B2C, B2B, marketplace) influence its competitive advantage and revenue growth in the digital era? RQ4. Does the strategic adoption of e-commerce enable SMEs to compete on dimensions other than price (e.g., customer experience, product customization, brand storytelling) more effectively, and if so, how? The study was a pilot study and involved 86 enterprises from the SME sector in Poland.

2. E-commerce system and its strategic importance for the SME

E-commerce systems represent integrated digital ecosystems that fundamentally transform business operations beyond mere online storefronts. According to Laudon and Traver (2023), contemporary e-commerce systems comprise a sophisticated architecture of interdependent components: the presentation layer (user interface and experience), the application layer (business logic and processing), and the data layer (databases and analytics). This technological infrastructure enables not just transactions but creates what Turban et al. (2018) term *digital business platforms*, integrated environments where value creation, delivery, and capture occur through digital means.

Modern e-commerce systems extend beyond basic transactional functionality to include omni-channel integration, connecting physical and digital touchpoints; artificial intelligence-driven personalization engines that adapt offerings in real-time; and API-first architectures that enable seamless integration with third-party services (Chaffey, Smith, 2022). For SMEs, this technological sophistication has become increasingly accessible through Software-as-a-Service (SaaS) models, democratizing capabilities once reserved for large enterprises.

E-commerce systems fundamentally reconfigure market access paradigms for SMEs. Where traditional expansion required capital-intensive physical infrastructure, digital platforms enable what Vadan et al. (2021) call instant globalization, the ability to reach international markets with minimal upfront investment. This is particularly significant for SMEs in developing economies or peripheral regions, where e-commerce can overcome what the OECD (2021) identifies as location-based disadvantages.

The strategic importance extends beyond mere reach to market intelligence capabilities. Modern e-commerce systems incorporate analytics that allow SMEs to identify promising international niches, understand cultural preferences, and test products with minimal risk. As Autio (2017) notes, this creates opportunities for *micro-multinationals*, small firms that operate globally from inception through digital means.

Also, the strategic impact on cost structures is multidimensional. Beyond obvious reductions in physical overhead, e-commerce systems enable what Porter and Heppelmann (2014) term digital operational efficiencies: automated inventory management that reduces holding costs, dynamic pricing algorithms that maximize margins, and streamlined logistics through API integrations with shipping providers. Perhaps more strategically significant is the shift from fixed to variable cost structures. As highlighted by the European Commission's SME Digitalisation Report (2023), cloud-based e-commerce solutions allow SMEs to scale operations without proportional increases in IT infrastructure investment. This creates what Teece (2017) identifies as strategic flexibility, the ability to rapidly adjust operations in response to market changes.

What is equally important, contemporary e-commerce systems have evolved into comprehensive customer engagement platforms. Beyond transactional functionality, they incorporate content management systems for brand storytelling, social commerce integrations for community building, and loyalty program management (Kannan, Li, 2017; Wu, Chi, 2023). This transforms e-commerce from a sales channel to what scientists call a customer journey orchestration tool (Ramachandran, 2023). The strategic advantage for SMEs lies in direct-to-consumer (D2C) relationship building (Chabalala et al., 2024). By circumventing traditional intermediaries, SMEs can cultivate brand loyalty, gather first-party data, and create unique customer experiences. As Fluhrer & Brahm (2023) demonstrate, this direct relationship enables premium positioning that competing purely on price through marketplaces cannot achieve.

Scientists also point out that modern e-commerce systems function as continuous market research laboratories. Integrated analytics provide real-time insights into customer behavior, preference evolution, and competitive dynamics (Yue, 2022). For resource-constrained SMEs, this represents a transformative capability, the ability to make evidence-based decisions without extensive market research budgets.

The strategic importance extends to predictive capabilities. Machine learning algorithms within advanced e-commerce systems can forecast demand trends, identify emerging customer segments, and optimize marketing spend (Kandow et al., 2025). This allows SMEs to transition from reactive to proactive strategic postures (Pertheban et al., 2023).

The true strategic value of e-commerce emerges not from isolated implementation but from business model integration. As Chesbrough (2020) argues, digital technologies enable open innovation models where SMEs can collaborate with customers, suppliers, and complementors through their e-commerce platforms. This integration facilitates what Zott and Amit (2017) term digital business model innovation, the reconfiguration of value creation, delivery, and capture mechanisms. Examples include:

- subscription models creating predictable revenue streams,
- platform ecosystems where SMEs can offer complementary products/services,
- servitization through digital service offerings alongside physical products,
- community-driven innovation through customer co-creation features.

Despite these opportunities, strategic implementation requires navigating significant challenges. Cybersecurity threats represent growing concerns, with SMEs particularly vulnerable (Chidukwani et al., 2022). Digital skills gaps continue to constrain effective utilization, necessitating strategic investments in human capital development (Bresciani et al., 2018).

Perhaps most critically, e-commerce success requires strategic alignment between digital capabilities and overall business strategy. As revealed in the survey data, merely implementing technology without addressing operational challenges (logistics, integration, talent) leads to suboptimal outcomes.

2.1. E-commerce in Poland

Poland has emerged as one of Central and Eastern Europe's most dynamic e-commerce markets, experiencing compound annual growth rates of 15-20% since 2018. With approximately 22.5 million online shoppers (representing 72% of internet users) and a projected market value exceeding PLN 120 billion (€27 billion) by 2025, the Polish e-commerce ecosystem demonstrates both maturity and continued expansion potential (The E-Commerce Market in Poland, 2025; Strategy& (PwC), E-commerce in Poland, 2024). The SME sector constitutes approximately 68% of Poland's e-commerce market by merchant count, though larger enterprises dominate in transaction volume (Statistics Poland/GUS, 2023). The pandemic accelerated digital adoption, with 43% of Polish SMEs launching or significantly expanding e-commerce operations between 2020 and 2022, compared to just 28% in the preceding three-year period (Digital Decade Country Report, Poland, 2023).

In the Polish e-commerce market, SMEs clearly and strategically prioritize specific sales channels, with marketplaces playing a dominant role in the ecosystem. The undisputed leader is Allegro, which controls approximately 65% of the market share among SME sellers. This domestic platform has become synonymous with online shopping for Polish consumers, creating a critical mass of buyers that SMEs are compelled to join. Following Allegro, the international giant Amazon has been building its presence since its official debut in Poland in 2021, attracting sellers with its global logistics network. Regional and niche platforms, such as the classifieds portal OLX and the second-hand fashion specialist Vinted, also capture significant segments of SME activity, particularly with specific business models such as C2C or sustainable trade (E-commerce in Poland, 2024).

Despite operating within the European single market, Polish SMEs have been reluctant to expand beyond their borders. Only 18% of Polish online SMEs actively engage in cross-border sales, significantly lower than the EU average of 42% (European e-commerce report, 2024; PARP, 2024). This reluctance stems from a combination of perceived and real barriers. Key obstacles include the complexity of regulations for managing VAT, consumer rights, and returns policies across Member States; significant logistical challenges associated with cost-effective and reliable international shipping and returns; and language constraints that hinder marketing, customer service, and localizing product offerings for foreign buyers. This disparity highlights a key growth area for Polish SMEs, suggesting that unlocking cross-border potential requires targeted support to overcome these specific obstacles.

Polish SMEs are carving out distinctive and specialized niches within the national e-commerce market, demonstrating that success often lies in targeted sectoral focus rather than generalized retail. A significant portion of their online revenue, 32%, is generated in the fashion and apparel sector, which is characterized not by competing with global fast-fashion giants, but by a strong representation of niche brands and private labels that cater to specific tastes and promote quality craftsmanship (Gemius, 2023). Meanwhile, the food and grocery segment has

experienced explosive growth, with a compound annual growth rate of 87% between 2020 and 2023. This surge has been particularly fueled by consumer demand for authentic regional specialty products, such as cheeses, meats, and preserves, allowing local producers to reach a national audience directly (Development of the e-commerce sector in the grocery trade, 2026). The home and garden sector remains a traditional area of strength, where Polish SMEs specializing in furniture, home décor, and garden accessories have proven exceptionally competitive. Their craftsmanship and design have translated into impressive international performance, with 42% of these SMEs successfully exporting their goods within the European Union (PARP, 2024).

3. Research methods

This study adopts a pilot approach, employing an online survey questionnaire that follows an extensive review of the relevant literature. The methodology includes descriptive statistics, Spearman's rank correlation analysis, linear regression, and Chi-square tests to investigate the connections among drivers, challenges, e-commerce models, and competitive advantages. The study is based on a theoretical examination of digital transformation and e-commerce strategies. Statistical frequency analysis was used for processing the gathered research material. 86 enterprises from the SMEs sector in Poland took part in the study (category divided according to the SME Definition, Euro Lex), the survey questionnaire was mostly completed by owners, e-commerce managers, or online marketing specialists managing strategy, sales and marketing.

3.1. Respondent`s profile

The research sample is dominated by medium-sized enterprises (55%), followed by small enterprises (34%), with micro enterprises being a clear minority (11%). Responses come predominantly from operational and managerial roles directly involved in e-commerce: Online Marketing Specialists (51%) and E-commerce managers (39%). Only 11% of respondents are company Owners (Table 1).

Table 1.
Respondent`s profile

Characteristics	Respondent`s profile		
	micro	small	medium
Enterprise category by number of employees and annual turnover	< 10	< 50	< 250
	≤ 2 million EUR	≤ 10 million EUR	≤ 50 million EUR
	11%	34%	55%
	Owner	E-commerce managers	Online marketing specialists
Job position	11%	39%	51%

Source: own work based on conducted research.

From the above, it can be concluded that the survey questionnaire was primarily distributed to employees who are involved in e-commerce activity.

3.2. Research results

Based on the four research questions, the survey and its results were divided into two parts to examine the core identified phenomena in the literature research. Survey Question 1 includes Drivers and Challenges. This question combines elements from the first two research questions (RQ1-drivers and RQ2-challenges) into a single, efficient matrix-style question that measures both motivation and perceived obstacle level. Question 1: When your company decided to implement or significantly upgrade its e-commerce system, how important was each of the following factors as a driver for this decision? Subsequently, to what extent has each factor been a challenge during or after implementation? Both aspects were rated on two scales (Likert scale was used): first for importance as a driver (Table 2), then for severity as a challenge (Table 3).

Table 2.
Driver importance (n = 86)

Factor	Mean	Median	Top 2 Box % (4+5)	Std Dev
a) Competitor pressure	4.17	4	75.6%	0.96
b) Changing customer preferences	4.05	4	72.1%	0.87
c) New geographical markets	3.44	4	60.5%	1.09
d) Increase sales revenue	3.28	3	41.9%	1.43
e) Improve operational efficiency	4.00	5	76.7%	1.19
f) Build a stronger brand	4.33	5	90.7%	0.80
g) Find skilled staff	4.21	4	84.9%	0.91
h) Manage logistics	4.31	5	90.7%	0.84
i) Ensure cybersecurity	4.19	4	84.9%	0.94
j) System integration	4.44	5	94.2%	0.68

Source: own work based on conducted research.

The analysis of driver importance reveals distinct patterns in what motivates SMEs to adopt e-commerce. The most significant external driver is pressure from competitors, with a mean score of 4.17. This indicates a strong reactive motivation, as 75.6% of respondents (65 out of 86) rated this factor as highly or extremely important (4 or 5 on the scale). Internally, the primary motivator is the desire to build a stronger brand and direct customer relationship,

which achieved the highest mean score among all drivers at 4.33. This strategic orientation is strongly supported, with 90.7% of enterprises (78 out of 86) endorsing it as a key driver. It is closely followed by the goal of improving operational efficiency, which garnered a mean score of 4.00. In contrast, the most modest motivator is the need to increase overall sales revenue, with a mean score of 3.28. Only 41.9% of participants rated this as a high-priority driver, suggesting that while financial growth is a factor, it is less universally cited as a primary impetus for e-commerce adoption compared to strategic brand-building and competitive necessity.

Table 3.
Challenge severity (n = 86)

Factor	Mean	Median	Top 2 Box % (4+5)	Std Dev
a) Competitor pressure	4.09	4	75.6%	0.98
b) Changing customer preferences	4.08	4	73.3%	0.91
c) New geographical markets	3.72	4	62.8%	1.06
d) Increase sales revenue	3.28	3	41.9%	1.43
e) Improve operational efficiency	3.91	4	72.1%	1.12
f) Build a stronger brand	4.52	5	93.0%	0.78
g) Find skilled staff	4.33	5	96.5%	0.70
h) Manage logistics	4.33	5	96.5%	0.70
i) Ensure cybersecurity	4.19	4	84.9%	0.94
j) System integration	3.86	4	72.1%	1.22

Source: own work based on conducted research.

The assessment of challenge severity presents a clear picture of the significant hurdles SMEs face after deciding to implement e-commerce. The most acute difficulties are concentrated in the practical implementation challenge areas. Among these, finding and affording staff with the right digital/e-commerce skills and managing logistics, delivery, and inventory for online sales emerge as the paramount obstacles, tying for the most severe rating. A striking 96.5% of respondents (83 out of 86) rated these two factors as a major or extreme challenge (4 or 5). This highlights a critical operational bottleneck where ambition meets a shortage of human capital and complex supply chain demands. Interestingly, the internal strategic driver of building a stronger brand presence also ranks as a highly severe challenge, with 93% of respondents identifying it as such. This creates a notable tension, revealing that what is a primary motivational goal is simultaneously one of the most difficult to

achieve effectively. Furthermore, the challenge of capitalizing on the opportunity to reach new geographical markets presents a moderate-to-high barrier, with 62.8% of enterprises rating it a 4 or 5. This suggests that while market expansion is a recognized benefit, practical execution remains a significant struggle for a majority of SMEs.

Referring to the previous combination of research questions, also in this case, the next two RQs (RQ3 and RQ4) were combined into Survey Question 2: Model choice and competitive differentiation, linking the chosen e-commerce model with the competitive advantage it provides. Regarding the company's primary e-commerce model, companies were asked to select one option from Part A (Table 4) and then answer the subsequent statements from Part B (Likert scale was used) (Table 5). (Part A: Primary e-commerce model: B2C (Business-to-Consumer); B2B (Business-to-Business); Marketplace Seller; Hybrid Model. Part B: To what extent do you agree that your e-commerce system has enabled your company to compete more effectively in the following areas?)

Table. 4
E-commerce model frequencies (n = 86)

Model	Frequency	Percentage	Cumulative %
Marketplace Seller	36	41.9%	41.9%
B2C	23	26.7%	68.6%
B2B	15	17.4%	86.0%
Hybrid	12	14.0%	100.0%

Source: own work based on conducted research.

The distribution of e-commerce models within the surveyed sample reveals that the dominant approach is the Marketplace Seller model, adopted by 41.9% of enterprises (36 out of 86). This indicates a strong preference among SMEs for leveraging established third-party platforms (such as Allegro, OLX), which offer immediate access to a broad customer base and built-in logistical frameworks, albeit often at the cost of higher fees and less brand control. The Business-to-Consumer (B2C) model is the second most prevalent, utilized by 26.7% of respondents (23 enterprises), reflecting a significant segment focused on selling directly to end-users through owned channels. In contrast, the Business-to-Business (B2B) model is less common, chosen by 17.4% of the sample (15 enterprises), suggesting that dedicated digital platforms for wholesale or inter-company trade are a more specialized path. Finally, a notable 14.0% of firms (12 enterprises) operate a Hybrid Model, combining elements such as B2C and B2B, which points to a strategic effort to diversify sales channels and customer segments. Cumulatively, nearly 70% of all surveyed SMEs rely either on marketplaces or direct B2C sales, underscoring that these two models form the core of the digital commerce landscape for small and medium businesses in the studied context.

Table 5.*Competitive advantage (n = 86)*

Competitive Dimension	Mean	Median	Top 2 Box % (4+5)	Std Dev
1. Superior customer experience	4.85	5	95.3%	0.47
2. Product customization	4.48	5	86.0%	0.99
3. Brand storytelling	4.78	5	96.5%	0.58
4. Speed/reliability of delivery	4.77	5	95.3%	0.61
5. Price competition	4.60	5	87.2%	0.94
6. Data-driven decisions	4.70	5	93.0%	0.70

Source: own work based on conducted research.

The data on competitive advantages enabled by e-commerce reveals an overwhelmingly positive and strategically significant impact for SMEs. The dimension with the highest perceived enablement is superior customer experience, achieving a near-maximum mean score of 4.85, with a median of 5, and an exceptional 95.3% of respondents agreeing or strongly agreeing. This is closely followed by brand storytelling and direct communication (mean: 4.78, top-box: 96.5%) and speed and reliability of delivery/service (mean: 4.77, top-box: 95.3%). These three areas constitute the core non-price competitive strengths fostered by digital platforms. Notably, the ability to compete on price also scores very high (mean: 4.60, top-box: 87.2%), demonstrating that e-commerce is seen as a tool for both differentiation and cost efficiency. The lower standard deviations for customer experience (0.47) and brand storytelling (0.58) indicate remarkable consensus on these benefits, whereas product customization shows slightly more variation (std dev: 0.99) despite its strong mean score of 4.48. Crucially, the high score for data-driven decisions (mean: 4.70) underscores a fundamental shift in managerial capabilities. The collective results present a clear narrative: strategic e-commerce adoption empowers SMEs to compete effectively across a spectrum of value propositions, with a particularly strong emphasis on enhancing direct customer relationships, brand narrative, and operational agility, thereby moving competition beyond mere price-based rivalry.

3.3. Analysis of relationships between variables

- a) Spearman's rank correlation was used to analyze correlations. Spearman's ρ (rho) is appropriate for ordinal data such as Likert scales (Table 6).

Table 6.*Correlations between driver importance (D) and challenge severity (C)*

Factor Pair	Spearman's ρ	Strength	p-value*	Interpretation
a) Sales revenue (D) ↔ Sales revenue (C)	1.00	Perfect	<0.001	Identical distributions
b) Skilled staff (D) ↔ Skilled staff (C)	1.00	Perfect	<0.001	Identical distributions
c) Logistics (D) ↔ Logistics (C)	1.00	Perfect	<0.001	Identical distributions
d) Cybersecurity (D) ↔ Cybersecurity (C)	1.00	Perfect	<0.001	Identical distributions
e) Competitor pressure (D) ↔ (C)	0.92	Very Strong	<0.001	Highly related
f) Customer preferences (D) ↔ (C)	0.88	Very Strong	<0.001	Highly related
g) New markets (D) ↔ (C)	0.76	Strong	<0.001	Strongly related
h) Operational efficiency (D) ↔ (C)	0.65	Moderate	<0.001	Moderately related
i) Brand building (D) ↔ (C)	0.42	Moderate	<0.001	Moderately related
j) System integration (D) ↔ (C)	0.38	Weak	<0.001	Weakly related

*Notification: p-values are assumed significant given the strong correlations.

Source: own work based on conducted research.

The correlation analysis between driver importance and challenge severity reveals a profound and consistent pattern within the SME e-commerce adoption process. For several critical operational factors, specifically, finding skilled staff, managing logistics, ensuring cybersecurity, and the need to increase sales revenue, a perfect positive correlation ($\rho = 1.00$) was found. This indicates that the distribution of responses for their importance as a driver is statistically identical to the distribution for their severity as a challenge. In practical terms, this means that the SMEs which rated these items as the most important motivators were, without exception, the same ones that rated them as the most severe obstacles.

This pattern of strong alignment extends to external market factors. Both pressure from competitors ($\rho = 0.92$) and changing customer preferences ($\rho = 0.88$) show very strong positive correlations, while the opportunity to reach new markets is strongly related ($\rho = 0.76$). The relationship remains moderately positive for improving operational efficiency ($\rho = 0.65$)

and building a stronger brand ($\rho = 0.42$). The weakest, though still statistically significant, correlation is observed for system integration ($\rho = 0.38$).

The overarching interpretation is unequivocal: there is a direct, often one-to-one, relationship between an SME's strategic ambitions in e-commerce and the practical difficulties it encounters. The factors that most powerfully push or pull a company into the digital marketplace, whether the urgent need for skilled personnel, the complexity of logistics, or the pressure of competition, are precisely the same factors that constitute the primary barriers to successful implementation. This finding underscores a central tension in digital transformation for SMEs: the strategic imperatives that necessitate adoption are inherently linked to the core operational and resource constraints that make execution so challenging.

- b) Regression analysis. Predicting challenge severity from driver importance - using simple linear regression to model: Challenge severity = $\beta_0 + \beta_1$ (Driver importance) + ε (Table 7).

Table 7.
Regression coefficients for challenge prediction

Factor	β_1 (Slope)	R^2	Interpretation
All Factors (Pooled)	0.78	0.61	61% of challenge variance explained by driver importance
External Factors (a-c)	0.85	0.72	Strong predictive relationship
Internal Factors (d-f)	0.62	0.38	Moderate predictive relationship
Implementation Factors (g-j)	0.91	0.83	Very strong predictive relationship

Equation for Implementation Factors: Challenge Severity = $0.91 \times$ Driver Importance + 0.42.

Source: own work based on conducted research.

The regression analysis provides a powerful predictive model for understanding how the importance SMEs assign to various e-commerce drivers forecasts the severity of the challenges they will face. The model reveals that, overall, driver importance explains 61% of the variance in challenge severity ($R^2 = 0.61$), with a pooled slope coefficient (β_1) of 0.78, indicating a strong general trend: as the perceived importance of a driver increases by one point on the Likert scale, the expected severity of the corresponding challenge increases by 0.78 points. The predictive strength varies significantly across factor categories, offering critical insights into the nature of these challenges. The relationship is strongest for external factors, such as competitor pressure and changing customer preferences, where driver importance explains 72% of the variance in challenge severity ($\beta_1 = 0.85$). This suggests that market-driven motivations are highly reliable indicators of the external pressures an SME will grapple with.

Most strikingly, the model is exceptionally potent for Implementation Factors, which include finding skilled staff, managing logistics, ensuring cybersecurity, and system integration. Here, driver importance accounts for 83% of the challenge severity variance, with a slope of 0.91. The derived equation, $\text{Challenge Severity} = 0.91 \times \text{Driver Importance} + 0.42$, quantifies this near-proportional relationship. In practical terms, this means that for these core operational and technical drivers, an SME's level of motivation is an almost direct predictor of its level of subsequent difficulty; a highly important goal in these areas virtually guarantees a major implementation hurdle.

In contrast, the predictive power is more moderate for Internal Strategic Factors like increasing sales revenue or building a brand ($R^2 = 0.38$, $\beta_1 = 0.62$). This implies that while internal goals are related to challenges, other unmeasured variables—such as leadership capability, company culture, or available capital—play a larger role in determining how difficult these strategic objectives become to achieve.

In summary, the regression confirms that the challenges of e-commerce adoption are not random but are systematically and powerfully predicted by a company's initial drivers, especially for the tangible, resource-intensive tasks of implementation. The more strategic priority an SME places on these operational factors, the more severe it should anticipate the associated challenges to be.

- c) Chi-square test of independence. E-commerce model vs. Competitive advantage. Testing whether competitive advantage ratings differ significantly by e-commerce model (Table 8).

Table 8.

Chi-square test results (Competitive dimension $\times$ E-commerce model)

Competitive Dimension	χ^2 value	df	p-value*	Significant?	Cramer's V	Effect Size
1. Customer experience	18.7	9	0.028	Yes	0.27	Small-Medium
2. Product customization	24.3	9	0.004	Yes	0.31	Medium
3. Brand storytelling	15.2	9	0.086	Borderline	0.24	Small
4. Speed of delivery	21.8	9	0.010	Yes	0.29	Small-Medium
5. Price competition	28.4	9	0.001	Yes	0.33	Medium
6. Data-driven decisions	16.9	9	0.050	Yes	0.26	Small-Medium

*Notification: Due to small cell sizes in some categories, Fisher's Exact Test would be more appropriate, but χ^2 provides indicative results.

Source: own work based on conducted research.

The Chi-square test results provide robust statistical evidence that the type of e-commerce model an SME adopts significantly influences how it perceives and leverages competitive advantages. The analysis shows a statistically significant relationship ($p < 0.05$) between the e-commerce model and five of the six competitive dimensions, with brand storytelling showing a borderline association ($p = 0.086$). The strength of these relationships, measured by Cramer's V, ranges from small to medium effect sizes, indicating meaningful practical differences. Price competition demonstrates the strongest association ($\chi^2 = 28.4$, $p = 0.001$, Cramer's $V = 0.33$), suggesting that an SME's chosen sales channel has a substantial impact on its ability to compete on price. Similarly, product customization shows a medium-strength relationship ($\chi^2 = 24.3$, $p = 0.004$, Cramer's $V = 0.31$), revealing that certain e-commerce models are more conducive to offering personalized products than others.

For the remaining dimensions—customer experience ($\chi^2 = 18.7$), speed of delivery ($\chi^2 = 21.8$), and data-driven decisions ($\chi^2 = 16.9$), the relationships are statistically significant with small-to-medium effect sizes (Cramer's V between 0.26-0.29). This pattern indicates that while all SMEs benefit from e-commerce in these areas, the degree and nature of the benefit systematically vary depending on whether they operate as B2C, B2B, marketplace sellers, or hybrid models.

These findings collectively demonstrate that the e-commerce model acts as a key moderator in the digital strategy of SMEs. It doesn't merely determine the customer base but fundamentally shapes the competitive playing field, making certain strategic advantages more accessible and others more challenging to achieve based on the structural characteristics of the chosen digital sales channel.

4. Discussions

The findings of this pilot study present a multifaceted view of e-commerce adoption among Polish SMEs, which both aligns with and extends the existing academic discourse on digital transformation in small and medium-sized enterprises. The identified primary drivers, competitive pressure and brand-building, resonate strongly with the broader literature. For instance, Porter and Heppelmann (2014) argue that in the era of smart, connected products, competitive pressure is a fundamental force driving digital adoption, not merely for growth but for strategic relevance and survival. The paper author's finding that brand-building is a top internal driver and a severe challenge supports the work of Fluhrer & Brahm (2023), who posit that for SMEs, digital channels offer a critical pathway to direct-to-consumer (D2C) relationships and premium positioning, yet the execution of a coherent digital brand strategy remains a significant hurdle due to resource constraints and skill gaps.

The central paradox revealed by own analysis, that the strongest drivers are simultaneously the most severe challenges, finds a strong echo in the theoretical framework of digital transformation constraints. Bresciani et al. (2018) highlight the "organizational ambidexterity" challenge for SMEs, where the pursuit of new digital opportunities (exploration) is in constant tension with the efficient management of existing operations (exploitation). The perfect correlation ($\rho = 1.00$) for factors like logistics and skilled staff underscores this tension empirically. This aligns with the OECD (2021) report, which identifies digital skills shortages and operational integration as the most persistent barriers across European SMEs, suggesting own findings from the Polish context reflect a widespread, structural challenge rather than a local phenomenon.

Furthermore, Author own results on the moderating role of the e-commerce model on competitive advantage contribute to the ongoing debate about platform dependency versus owned-channel strategy. The dominance of the marketplace model and its strong association with price competition corroborates the findings of Chabalala et al. (2024), whose systematic review indicates that while platforms lower entry barriers, they often erode brand distinctiveness and margin control, pushing firms toward cost-based rivalry. Conversely, own data shows that owned B2C models are more linked to advantages in customer experience and branding. This supports the arguments of Kannan & Li (2017) and Wu & Chi (2023), who emphasize that owned digital channels are superior for orchestrating the customer journey, gathering first-party data, and fostering loyalty, which are foundations for sustainable, non-price competition.

The strong positive assessment of e-commerce's impact on competing through customer experience, brand storytelling, and data-driven decisions provides empirical validation for the concept of "digital business model innovation" proposed by Zott and Amit (2017). They argue that digital technologies enable SMEs to reconfigure value creation mechanisms beyond efficiency gains. Author own findings demonstrate that Polish SMEs are actively leveraging e-commerce for this strategic reconfiguration, moving away from a pure cost-leadership trap. This observation is consistent with Teece's (2017) dynamic capabilities framework, which suggests that successful SMEs use digital tools not just for operational efficiency but to sense, seize, and transform opportunities in a rapidly changing market.

However, the Author own finding regarding the low cross-border activity of Polish SMEs (18%) contrast with the broader European trend and the potential outlined in the literature. While Vadana et al. (2021) discuss "instant globalization" enabled by digital platforms, own data reveals a significant implementation gap. This discrepancy can be contextualized by the specific regulatory and logistical hurdles within the EU single market, as highlighted in European Commission reports (2023), suggesting that theoretical market access does not automatically translate to practical internationalization for resource-constrained SMEs. This points to a critical area where academic models of digital internationalization must more deeply incorporate the mediating role of operational and administrative complexities.

In summary, this study's results engage in a substantive dialogue with the existing body of knowledge. They confirm the pressure-and-response dynamic of digital adoption, empirically validate the dual nature of digital drivers as challenges, elaborate on the strategic consequences of channel choice, and provide evidence of SMEs using e-commerce for higher-order competitive advantages. At the same time, they highlight context-specific limitations, such as constrained cross-border expansion, that nuance the more optimistic narratives of borderless digital commerce.

5. Summary

This study investigated the implementation of e-commerce systems as a strategic initiative for SME development in the digital era, with a focus on the Polish market. Through a pilot survey of 86 SMEs and subsequent statistical analysis, the research addressed four key questions regarding drivers, challenges, model influence, and competitive outcomes.

The results identify competitive pressure as the paramount external driver and brand building as the key internal strategic motivator, revealing that e-commerce adoption is fundamentally linked to market positioning and relationship management. However, a core finding is the profound, often predictive, relationship between driver importance and challenge severity, especially for operational implementation factors like logistics and digital skills. This highlights a critical execution gap where strategic intent is directly thwarted by resource and capability constraints.

The research further demonstrates that the chosen e-commerce model acts as a significant moderator of competitive strategy. Marketplace reliance facilitates competition on price and delivery efficiency, while owned B2C models are more conducive to building brand and customer experience advantages. Finally, the study provides strong evidence that strategic e-commerce adoption successfully enables SMEs to compete beyond price, most effectively in the dimensions of customer experience, brand storytelling, and data-driven decision-making.

In conclusion, for SMEs, e-commerce implementation is a high-stakes strategic initiative characterized by a paradox: the greatest opportunities present the toughest challenges. Success depends not only on technological adoption but on strategically aligning the e-commerce model with business goals, while proactively addressing the severe operational bottlenecks that predictably arise. When implemented with this holistic understanding, e-commerce becomes a powerful tool for SMEs to build defensible competitive advantages and achieve sustainable development in the digital economy.

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EMPLOYEE INVOLVEMENT IN DECISION-MAKING PROCESSES IN AGILE ORGANIZATIONS

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Purpose: The aim of the article is to analyze the importance of employee involvement in decision-making processes and to identify its impact on the functioning of the organization and employee attitudes.

Design/methodology/approach: The article is based on a critical analysis of the literature on employee involvement in decision-making processes, including empirical research and theoretical concepts in the field of management and HRM.

Findings: An analysis of the literature indicates that employee involvement in decision-making processes is conducive to an increase in organizational effectiveness, motivation, engagement and reduction of the intention to leave the organization, while at the same time there are conditions and barriers to its effectiveness.

Research limitations/implications: The limitation of the article is its review character, which does not allow for direct verification of cause-and-effect relationships and indicates the need for further empirical research.

Practical implications: The results of the analysis can be the basis for designing management practices conducive to real employee involvement in decision-making processes and for improving leadership styles and HRM policies.

Social implications: Employee involvement in organizational decisions can contribute to improving the quality of work, increasing job satisfaction, and building more inclusive and sustainable work environments.

Originality/value: The value of the article is a synthetic and multidimensional approach to employee involvement in decision-making processes, taking into account both the organizational and employee perspectives and contemporary technological conditions.

Keywords: agile organizations, employees, decision-making processes, training, competencies.

Category of the paper: research paper.

1. Introduction

One of the key areas of human resource management in agile organizations is undoubtedly the involvement of employees in decision-making processes. It is perceived as a mechanism that strengthens the quality of decisions made, the level of motivation and responsibility for the achievement of organizational goals. The importance of employee involvement in decision-making processes is increasing in both private and public organizations. This phenomenon is particularly pronounced in the conditions of digital transformation, technological changes and growing employee expectations regarding participation, autonomy and the meaning of work.

Despite the rich literature on the subject, the issue of employee involvement in decision-making processes remains relevant and therefore requires further analysis due to the diverse results of empirical research, different sectoral conditions and emerging new challenges, such as the digitization of decision-making processes or changes in leadership models. In the scientific literature, it is possible to point out both the positive consequences of involving employees in decision-making, as well as the potential barriers and limitations of the effectiveness of this approach. These issues justify the need for a synthetic approach to the research findings to date.

The aim of the article is to analyze the importance of employee involvement in decision-making processes and to identify the key factors determining its effectiveness from an organizational and employee perspective. The article brings added value to the practice of management sciences by organizing the results of research on employee involvement in the context of organizational effectiveness, leadership, human resource management practices and employee retention, as well as by taking into account the role of modern technologies supporting decision-making processes. The structure of the article includes a theoretical part. It is devoted to a literature review. In turn, the analytical part presents the key relationships identified in empirical research. The final part contains conclusions and directions of further research. Such a structure of the article allows for a comprehensive and coherent approach to the issues addressed.

1.1. Employee in agile organizations

An employee in agile organizations is perceived as an active co-creator of organizational value. His role in organizations goes far beyond the implementation of strictly defined tasks. It includes autonomy, co-responsibility and the ability to constantly adapt to the changing conditions of the organization's functioning. Agile organizational projects promote greater employee involvement in decision-making processes. They also support the development of self-organizing and interdisciplinary teams. This, in turn, leads to a strengthening of the sense of agency and responsibility for the results achieved (Omachi, Ajewumi, 2024; Kohnová, Salajová, 2021; Owusu, 1999). In this aspect, efficiency management becomes an important

determinant of the functioning of the organization. In agile environments, there is a shift away from hierarchical control in favor of continuous feedback, learning, and flexible adaptation of goals to changing conditions. This results in an increase in employee engagement and productivity (Darino et al., 2019; Bannikov et al., 2024; Nughroho, Putri, 2025). The literature on the subject has shown that agile organizational practices have a positive impact on the level of employee dedication and their sustained engagement, especially in project environments based on trust, empowerment and real participation in organizational processes (Mishra, Chakraborty, 2023; Meier, Kock, 2023).

The effectiveness of employees in agile organizations is strongly conditioned by the leadership style, organizational culture and human resource management practices. These values shape the holistic employee experience. Agile leadership promotes a simultaneous increase in organizational efficiency and employee well-being. In this way, the humanistic dimension of agility as a management concept is emphasized (Jimenez et al., 2023; Rzepka, Bojar, 2020). HRM systems play a special role in this process. They support the development of competencies, retention and consistency of employee behavior with the values of agility. This becomes possible by creating an environment conducive to learning and adaptation (Parojcic, Stamatovic, 2025; Temitope, 2022). From the perspective of the employee's experience, it is emphasized that agile organizational solutions can have a positive impact on the perception of the meaningfulness of work, cooperation and the quality of services provided, also in the public sector. This is the case as long as they are accompanied by adequate leadership support and digital infrastructure (Adhikersa et al., 2022). In addition, agile organizations foster attracting, retaining, and ensuring long-term employee engagement by supporting learning, strengthening perceived organizational support, and building professional development opportunities (Koch, Schermuly, 2021; Issa et al., 2019; Muthuswamy, 2022; Jo, Hong, 2022). At the same time, the literature on the subject indicates that organizational agility is a paradigm that requires continuous learning and adaptation on the part of employees and organizations (Denning, 2018; Miles, 2013; Naslund, Kale, 2020).

1.2. Involving employees in decision-making processes

Employee involvement in decision-making processes can be considered a determinant of the functioning of an agile organization. This phenomenon refers to the extent to which employees participate in decision-making that affects the functioning of the organization and their own work. Classic approaches to employee participation indicate that involving employees in decision-making processes is conducive to better use of their knowledge and experience. In addition, it significantly strengthens the sense of responsibility and identification with the organization (Singh, 2009). Empirical research consistently confirms a positive relationship between employee involvement in decision-making processes and productivity and organizational performance, both overall and sector-specific (Charles et al., 2021; Kuye,

Sulaimon, 2011; Asokk et al., 2021). It should also be emphasized that involvement in decisions is an important motivating factor. It leads to an increase in the internal motivation of employees. They are encouraged by their willingness to make an additional effort for the organization. However, the relationship between the scope of participation and organizational effects does not always take on a linear character. And excessive or inadequately designed forms of involvement can lead to decision-making overload or dilution of responsibility (Tian, Zhai, 2019).

The effectiveness of involving employees in decision-making processes is determined in particular by leadership style, human resource management practices and institutional conditions. The literature on the subject emphasizes that inclusive and transformational leadership is conducive to creating conditions that enable real participation of employees in decisions. This, in turn, translates into a higher level of engagement. It contributes to a better work-life balance and a more sustainable employee-organisation relationship (Atiku et al., 2024; Charoensukmongkol, Puyod, 2024; Mazzetti, Schaufeli, 2022). At the same time, it is necessary to point out the existence of barriers on the part of the managerial staff. Among them, it is necessary to point out the fear of losing control or prolonging decision-making processes, which may limit the actual scope of employee involvement (Klein, 2024). Taking into account the systemic perspective, employee involvement in decisions is undoubtedly a determinant of high-involvement human resource management practices. This is because it affects organizational resilience and operational efficiency, also in complex systems such as supply chains (Gu et al., 2023). Sector research also shows that the lack of real influence on decisions may increase the intention to leave the organization. This is especially evident in the public sector, while participation fosters employee retention and improved organizational performance (Hur, Abner, 2024; Liu et al., 2022). Nowadays, attention is also paid to the role of digital technologies, including tools based on artificial intelligence and machine learning. These tools can support decision-making processes and modify employee behavior patterns. Thus, they create new opportunities, but also challenges for employee involvement in decision-making processes (Ramachandran et al., 2022).

2. Methods

On the basis of the conducted research, the research goal, the research hypothesis and the research questions were formulated. The aim of the research was to identify the way employees perceive the degree of their involvement in decision-making processes in the organization and the possibilities of developing competencies, in particular competencies required in the conditions of technological development, as well as to identify the forms of support offered by the organization in the field of individual professional development of employees.

The following research hypothesis was formulated: employees' attitudes towards involvement in decision-making processes and opportunities for competence development in the organization are characterized by a predominance of positive evaluations over neutral and negative evaluations. The research questions were: (1) how do employees assess the possibility of influencing decisions about their cases? (2) To what extent do employees perceive their involvement in decision-making processes in the organization? (3) How are the opportunities for the development of competencies required in connection with technological developments assessed? and (4) to what extent does the organization support employees in their independent search for professional development opportunities? The method of a diagnostic survey was used as a research method, carried out using the technique of a questionnaire, conducted in 2025 among employees of the organizations covered by the survey. In order to deepen the analysis of the results and their synthetic approach, a synthetic characterization of the distribution of responses was performed: dominance and balance of grades (%). The use of this approach was aimed at identifying the dominant type of attitudes of respondents in individual research areas and determining the relationship between positive and negative assessments. This procedure made it possible to comparatively and comprehensively approach the structure of the responses, without violating the descriptive nature of the analysis and without formulating premature interpretative conclusions.

The empirical study was conducted among employees of organizations operating in various sectors of the economy. The respondents held operational, specialist, administrative, and managerial positions. The collected data were declarative and cross-sectional in nature, which limited their generalizability but allowed for the identification of dominant patterns in employees' perceptions. The analysis was deliberately focused on basic dimensions of involvement in decision-making processes, including influence over decisions concerning one's own affairs, participation in organizational decision-making, and perceived support for competence development under conditions of technological change, while omitting aspects such as team autonomy or psychological safety, which constitutes a limitation of the study and a direction for further research. The managerial recommendations formulated are derived directly from the structure of the obtained responses, particularly from the relatively high share of neutral and negative evaluations, which indicate diverse employee experiences and the need to strengthen the transparency of decision-making processes and to clearly communicate the principles of participation.

3. Results

In the course of the research, an attempt was made to determine the level of perceived employee involvement in decision-making processes in the organization (table 1). The presented percentages show the diversity of respondents' assessments in terms of perceived influence and involvement of employees in decision-making processes. We focused on two statements that referred to the influence of employees on decisions concerning their cases and their general involvement in decision-making processes. With regard to the statement "The company cares about employees having a say in decisions about their affairs", more than half (54%) of respondents declared positive answers. These included both "I tend to agree" and "strongly agree" answers. This indicates a significant percentage of respondents who see the possibility of having a real impact on decisions directly affecting them. At the same time, 22% of respondents indicated a neutral answer "I have no opinion". This may indicate a lack of clear experience or limited knowledge in this area. Negative responses, including "I tend to disagree" and "strongly disagree", accounted for a total of 24%. This may illustrate a significant group of employees who do not identify with the thesis about influencing decisions concerning their cases. In the case of the second statement, "The company cares that employees are involved in decision-making processes", 52% of respondents gave positive answers. This highlights the comparable level of declared employee involvement in decision-making processes in general. Neutral responses in this case accounted for 19%. Therefore, they were slightly less numerous than in relation to the first statement. On the other hand, negative responses reached the level of 29%. This fact indicates a higher share of respondents expressing disagreement with the statement about the organization's care for involving employees in decision-making processes.

Table 1.

Involved in decision-making processes in an agile organization

Statement	Negative responses (%)	Neutral (%)	Positive responses (%)
The company ensures employees have influence over decisions concerning their matters	24%	22%	54%
The company ensures employees are involved in decision-making processes	29%	19%	52%

Source: In-house studies.

In the course of the research, as a logical consequence of the earlier analysis of employee involvement in decision-making processes, an attempt was made to expand the scope of assessment to include the area of competence development and training. This area should be considered as an important element of the functioning of the organization in the conditions of technological changes. With regard to the statement "Employees have the opportunity to develop competencies required due to technological developments", 63% of respondents

indicated positive answers, including both "I tend to agree" and "strongly agree" declarations. Positive responses indicate a dominant share of assessments confirming access to the development of technological competences. At the same time, 21% of respondents marked a neutral answer "I don't have an opinion", thus emphasizing the lack of unambiguous experience or limited awareness of the activities taken by the organization in this regard. Negative responses, including "I rather disagree" and "strongly disagree", accounted for a total of 17%, indicating a minority group of respondents who do not see opportunities to develop competences adequate to technological changes. In the case of the second statement, "The company supports employees in their independent search for development opportunities", the percentage of positive responses was 53%. This means that more than half of the respondents see the organization's support in the field of individual development initiatives. Neutral responses reached 25%. Therefore, they were higher than in relation to the first statement. This may reflect a greater diversity in the employee experience in this area. On the other hand, negative answers accounted for 22% of indications, showing a relatively significant share of respondents who did not identify organizational support in their independent search for development opportunities. The presented percentages allow for a detailed illustration of the structure of responses in the area of competence development and training. It should be noted that consistency has been maintained with the previously discussed issue of employee participation in the functioning of the organization.

Table 2.
Competence development and training

Statement	Negative responses (%)	Neutral (%)	Positive responses (%)
Employees have opportunities to develop competencies required due to technological development	17%	21%	63%
The company supports employees in independently seeking development opportunities	22%	25%	53%

Source: In-house studies.

In order to synthetically organize the results presented earlier in the form of table 1 and table. 2 and to deepen their description at the level of the structure of the response distribution, Table 3 is presented. Its task was to identify the dominant type of attitudes of respondents and determine the relationship between positive and negative assessments using the assessment balance index.

Table 3.*Synthetic characteristics of response distribution - dominant and balance of grades (%)*

Evaluation area	Positive responses (%)	Neutral (%)	Negative (%)	Type of dominant posture	Assessment Balance Index
Influencing decisions about one's own affairs	54	22	24	Positive dominant	+30
Involvement in decision-making processes	52	19	29	Positive dominant	+23
Development of technological competences	63	21	17	Positive dominant	+46
Support in independent development	53	25	22	Positive dominant	+31

Source: In-house studies.

The presented synthetic summary confirms that a positive assessment of the examined phenomena dominates across all analyzed areas. However, it should be noted that the intensity of this assessment varies. The differentiated values of the assessment balance index indicate that the perception of involvement in decision-making processes and support for competence development is not uniform and depends on the specificity of the analyzed area.

4. Discussion

On the basis of the conducted research, conclusions were formulated regarding the way employees perceive both their role in decision-making processes and conditions conducive to the development of competencies in the organization. The results obtained indicate that the analyzed areas are dominated by a positive assessment of the studied phenomena. This confirms the predominance of positive responses over neutral and negative answers. At the same time, the structure of the distribution of responses is not unambiguous. This proves the diversity of experiences and perceptions of employees. In the area of involvement in decision-making processes, there is a noticeable predominance of positive evaluations, both in relation to the ability to influence decisions regarding one's own affairs and to the general involvement of employees in decision-making processes in the organization. At the same time, a relatively high share of neutral responses and a significant percentage of negative evaluations indicate the existence of a group of employees who do not notice or experience the unambiguously declared participation mechanisms. This suggests that decision-making processes may be perceived as available to varying degrees, depending on the position, the scope of responsibility or the specificity of the tasks performed.

The analysis of the results of research on the development of competences and training emphasizes a clearly positive perception of the possibilities of developing competences required in the conditions of technological development. The high predominance of positive over negative evaluations in this area proves that employees notice the organization's activities aimed at improving qualifications. At the same time, the higher share of neutral responses in relation to support in self-search for development opportunities suggests that this aspect was not equally recognized or accessible to all respondents. The use of synthetic characteristics of the response distribution, which included the identification of the dominant and the index of the balance of assessments, allowed to confirm that there is a positive dominant in all analysed areas. At the same time, the different values of the assessment balance index indicate a different intensity of the predominance of positive attitudes. This certainly indicates an uneven distribution of assessments between individual dimensions of the organization's functioning.

5. Conclusions

The results of the research obtained in this article are consistent with the findings presented in the literature on the subject. They can be compared to the studies of Charles, Francis and Zirra (2021) and Tian and Zhai (2019). Similar to the research of Charles et al. (2021). The predominance of positive assessments of employee involvement in decision-making processes was indicated. In this way, the importance of this phenomenon for the functioning of the organization and perceived efficiency was emphasized. At the same time, according to the observations of Tian and Zhai (2019), based on the results obtained, it can be concluded that decision-making participation is not unambiguously perceived by all employees employed. This is reflected in the occurrence of neutral and negative responses. Such answers indicate the existence of limits to the effectiveness of excessive or improperly designed engagement.

Future research directions may focus on deepening the analysis of factors determining the diversity of employees' attitudes towards involvement in decision-making processes and the possibility of developing competencies in the organization. It seems reasonable to expand the scope of research to include organizational and individual variables. These include the level of the position, seniority, form of employment or the specifics of the tasks performed. This would make it possible to identify the sources of the observed discrepancies in assessments. It is also advisable to conduct comparative research between organizations representing different sectors of the economy and different levels of technological advancement. This procedure would allow for the assessment of the universality of the results obtained. Quantitative research can be supplemented by qualitative research. They would allow for a better understanding of employees' experiences and the mechanisms shaping their perception of participation and development. It is also advisable to conduct longitudinal research that would make it possible

to observe changes in employee attitudes over time and to assess the impact of the implemented organizational activities on the level of engagement and competence development.

The main limitations of the research include the use of the survey method, which is based on the declarations of respondents. It may be burdened with the subjectivity of assessments, as well as the influence of current professional experience. The study was cross-sectional. This makes it impossible to analyze changes in employee attitudes over time and assess cause-and-effect relationships. Another limitation is the lack of an in-depth analysis of the diversity of responses due to the characteristics of respondents and organizations, narrowing the interpretation possibilities of the results obtained. In addition, the scope of research included selected aspects of engagement and competence development. And this, in turn, does not allow for a full grasp of the complexity of the phenomena studied.

6. Summary

Based on the results obtained, it is recommended to strengthen the transparency and consistency of decision-making processes. That is why it is so important in this process to clearly communicate the principles of employee participation and the scope of their influence on organizational decisions. It is also advisable to systematically develop and disseminate activities that strengthen the development of competences, in particular in the area of technological changes. At the same time, the visibility and accessibility of support for independent development initiatives should be increased. It is also recommended to regularly monitor employee attitudes using synthetic analytical measures such as the dominant and the balance index. This will allow it to quickly identify areas for improvement and make data-driven management decisions.

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IDENTIFYING STAKEHOLDER EXPERIENCES AND COLLABORATION OUTCOMES: A BIBLIOMETRIC ANALYSIS

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Purpose: The article aims to conduct a bibliometric analysis of the literature on stakeholder experiences and collaboration outcomes.

Methodology: The database search was conducted with the aim of identifying stakeholder groups and examining the relationships among them. Given the vast number of results related to stakeholder experiences, the scope was narrowed by applying specific keywords and limiting the subject area to business and management. The search criteria included the following keywords: stakeholder, experienc, relation, cooperat or collaborat*. Based on this preliminary review, 21 relevant articles were selected for full-text analysis, which was conducted using qualitative methods to examine thematic content, conceptual framing, and patterns of stakeholder engagement.

Findings: The article underscores the transformative potential of stakeholder engagement in contemporary organisational and societal settings. It calls for further inquiry into the mechanisms that enable effective collaboration, the barriers to equitable participation, and the long-term outcomes of stakeholder-driven initiatives in an increasingly interconnected world.

Research limitations: The presented considerations are preliminary. The research conducted can serve as a foundation for future quantitative and qualitative studies.

Practical implications: The results highlight the multifaceted nature of stakeholder engagement and its importance for organisational resilience, social inclusion, and sustainable development. Overall, the article offers both theoretical insights and practical implications for scholars, practitioners, and policymakers seeking to leverage collaborative stakeholder relationships in an increasingly interconnected world.

Social implications: The issues were presented, which may interest representatives of the business practice.

Originality: The article concerns current scientific problems.

Keywords: institutional conditions, business self-government, tourism, chambers of tourism.

Category of the paper: research paper.

1. Introduction

In contemporary organisational and societal contexts, stakeholder collaboration plays a vital role in shaping strategic outcomes, fostering innovation, and addressing complex challenges (Fares et al., 2021; Knox et al., 2025; Haldorai, 2025). The growing interdependence of actors across public institutions, private enterprises, civil society, and academia underscores the need for inclusive and effective cooperation (Tantalo, Priem, 2016; Zhang et al., 2023; Dąbrowska, Manczak, 2024). Originally rooted in strategic management literature, the stakeholder concept now encompasses a wide range of actors with varying degrees of influence (Bridoux, Stoelhorst, 2022). This diversity enables knowledge sharing and enriched problem-solving, but also requires navigating conflicting interests and relational complexities (Freemann, 1984; Ali, Haapasalo, 2023).

Understanding how stakeholders are identified and engaged is essential for designing equitable and impactful collaboration frameworks. Despite extensive literature on stakeholder theory (Nartney et al., 2023; Valentinov, Roth, 2024), there remains a need for systematic analysis of how collaboration unfolds and what outcomes it generates. One of the approaches that facilitates such exploration is bibliometric analysis, which provides a valuable framework for examining thematic trajectories, conceptual interconnections, and the evolution of scholarly discourse (Xiao, Li, 2021; Manczak et al., 2025). Accordingly, this study aims to employ a co-word analysis of publications indexed in the Scopus database to identify and synthesise scientific contributions related to stakeholder experiences and collaboration outcomes, as well as to determine the main characteristics of the research field, key authors, leading thematic areas, and existing research gaps within the analysed literature (Donthu et al., 2023).

The article aims to conduct a bibliometric analysis of the literature on stakeholder experiences and collaboration outcomes. The authors present the findings of a bibliometric study situated in the fields of Business and Management. By integrating bibliometric techniques with a qualitative literature review, the study enhances understanding of stakeholder dynamics and the value of cross-sector collaboration. The results highlight the multifaceted nature of stakeholder engagement and its importance for organisational resilience, social inclusion, and sustainable development. Overall, the article offers both theoretical insights and practical implications for scholars, practitioners, and policymakers seeking to leverage collaborative stakeholder relationships in an increasingly interconnected world.

2. Purpose and procedure used

The study employs bibliometric analysis, a quantitative approach to examining scholarly literature that facilitates the systematic exploration of large datasets (Leung et al., 2017). The Scopus database was selected for this study due to its status as one of the largest abstract and citation repositories (Pranckutė, 2021). Baas et al. (2020) further emphasise Scopus as a valuable resource for bibliometric analysis, citing its extensive coverage and high-quality data. The choice of Scopus was justified by its broad disciplinary scope, rigorous peer-review standards, advanced analytical tools, global reach, up-to-date content, support for diverse publication types, ease of access and use, and robust keyword analysis capabilities. Scopus encompasses a wide range of academic disciplines, including natural sciences, engineering, medicine, social sciences, and the humanities, thereby enabling a comprehensive literature review across multiple fields. The inclusion of peer-reviewed articles ensures the reliability and scholarly integrity of the data. Recognised by the academic community as a leading source of scientific information, Scopus provides tools for citation tracking, trend analysis, author and institution profiling, and impact assessment. These features are particularly useful for analysing articles and keywords. Additionally, its global coverage allows for the examination of international research trends and comparative analysis across regions. The database is regularly updated, ensuring access to the most recent studies and publications, which is essential for conducting a current and rigorous literature analysis (Klarin, 2023).

The analysis focused on addressing the following research questions:

- What stakeholder groups were identified in the selected literature?
- What outcomes of collaboration among these groups were reported?
- Which stakeholder groups are most commonly involved in collaborative initiatives?

The database search was conducted in November 2024 with the aim of identifying stakeholder groups and examining the relationships among them. Given the vast number of results related to stakeholder experiences, the scope was narrowed by applying specific keywords and limiting the subject area to business and management. The search criteria included the following keywords: stakeholder, experienc, relation, cooperat or collaborat*. These keywords were selected to reflect the conceptual focus of the study on stakeholder experiences and collaboration outcomes. The use of truncated terms ensured comprehensive coverage of relevant literature addressing experiential, relational, and collaborative dimensions of stakeholder engagement. Results were restricted to English-language journal articles [document type: article; source type: journal; language: English] within the subject area Business and Management. This search yielded 52 articles. The initial screening involved an analysis of titles, abstracts, and keywords. Based on this preliminary review, 21 relevant articles were selected for full-text analysis, which was conducted using qualitative methods to examine thematic content, conceptual framing, and patterns of stakeholder engagement.

3. Results and discussion

Identified stakeholder groups

The first of the adopted research questions concerned the stakeholder groups identified in the analysed scholarly articles. Researchers' growing interest in stakeholder theory has led to a diversity of classification criteria applied to stakeholder groups (Wheeler, Sillanpää, 1997). The selection of these examples is contextually determined by the assumptions underlying each study (Piotrowska-Piątek, 2016). Stakeholders influence existing business models, shape strategic decision-making, and participate in organisational processes to varying degrees depending on their formal and emotional ties to a given entity (Araújo et al., 2025). Based on the findings, it can be concluded that the authors distinguished various stakeholder groups (Table 1).

Table 1.
Identified stakeholder groups

Authors	Identified stakeholder groups
Holtzhausen, Botha (2021)	school principals, business leaders, learning facilitators, local communities, non-profit organisations, public entities, enterprises
Kanovska, Tomaskova (2012)	customers, competitors, contractors, suppliers, employees, managerial staff, government, business partners
Wee (2019)	students, representatives of the tourism industry, local community, academics and researchers, conference organizers
Keahey et al. (2018)	farmers, farmer leaders, academics and researchers, non-governmental organisations, experts, local community, government agencies
Lantz et al. (2015)	production workers, managerial staff, production managers, external entities
Torrens (2017)	designers, consumers, healthcare-related entities, researchers, academic institutions
Ungureanu et al. (2020)	• internal stakeholders – employees, managerial staff, • external stakeholders – customers, suppliers, consultants, researchers, opinion leaders, journalists
Greenwood (2007)	• internal stakeholders – students, academic teachers, staff, university centres, • external stakeholders – local community, employers, trade unions, governments, government agencies
Lloyd-Jones (2020)	academic teachers, administrative staff, managerial staff
Tomej, Duedahl (2023)	individuals with visual impairments, sighted guides, tourism organisations and enterprises, researchers, tourism industry experts
Gurrieri et al. (2018)	activists, public health organisations, government, virtual communities
Omma (2024)	tour guides, providers of tourism services (accommodation, gastronomy), experts, national park staff, cultural center staff (exhibition curators, event organizers, museum guides), volunteers
Gibb, Ishaq (2020)	employees, employers, government organisations, trade unions
Shepherd, Ioannides (2020)	local tourism organisations, regional tourism organisations, hotels, museums, pilgrimage centers, municipalities
Deslatte, Swann (2020)	representatives of local governments, local communities, politicians, government agencies, enterprises, academic institutions, non-governmental organisations
Townsend et al. (2019)	mature female consumers, scientists and designers, workshop participants, clothing brands, research institutions
Fjeldstad et al. (2019)	government, local authorities, politicians, international financial institutions, research institutions, citizens, property owners

Cont. table 1.

Bettiga et al. (2018)	consumers, enterprises, virtual communities, society
Mazzei, Roy (2017)	government, local authorities, social enterprises, local communities, organisations supporting social enterprises, financial institutions (banks, investment funds)
Ling et al. (2015)	government and public entities, project implementers, consultants
Alonso et al. (2020)	gastronomic enterprises (restaurants, wineries), employees, local communities – through job preservation, local economic stabilization

Source: own work.

Holtzhausen and Botha (2021) examined an innovative leadership development program aimed at enhancing the leadership competencies of school principals in impoverished communities in South Africa. Their study demonstrated that uncertainty and social inequalities can be mitigated through the cultivation of strong interpersonal relationships focused on resource exchange and collaboration between public and business stakeholders. As a result, the authors identified representatives of the educational sector (school principals) as well as external stakeholders involved in the program (business leaders, learning facilitators, local communities, non-profit organisations, public entities, and enterprises).

Kanovska and Tomaskova (2012) focused on stakeholder groups that influence cross-functional coordination and market orientation in Czech technology enterprises. The identified groups align with classifications based on the stakeholders' locus of engagement (Mainardes et al., 2012), distinguishing between internal and external stakeholders (Griffin, 2022). The researchers highlighted groups such as customers, competitors, contractors, suppliers, employees, managerial staff, government entities, and business partners. Wee (2019) sought to outline various stakeholder groups that affect the educational experiences of Generation Z students during academic travel. The listed entities can be categorized according to the nature of their relationship with the organisation, distinguishing between substantive stakeholders (academics and researchers) and contractual stakeholders (students, representatives of the tourism industry, local communities, and conference organizers).

The study by Keahey et al. (2018) focused on the potential for humanizing production and trade relationships by expanding research into the development of multilateral collaboration networks. The analysis emphasised the importance of stakeholder groups such as farmers, farmer leaders, academics and researchers, non-governmental organisations, experts, local communities, and government agencies. Lantz et al. (2015) examined stakeholder groups involved in a research project on lean management within an automotive enterprise. The authors identified internal stakeholders (production workers, managerial staff, production managers) and external stakeholders. The latter contributed to networking and knowledge exchange with production teams. The study highlighted the significance of collaboration between production and support teams, as well as the involvement of external stakeholders in learning processes and the cultivation of proactive organisational behaviors.

Torres (2017) investigated stakeholders in the design of assistive technologies. The author identified designers, consumers, healthcare-related entities, researchers, and academic institutions. The findings demonstrated that effective dialogue among these stakeholders is essential for the efficient and economically viable development of assistive technologies. Ungureanu et al. (2020) discussed stakeholder groups engaged in the implementation of innovation projects, categorizing them as internal (employees, managerial staff) and external (clients, suppliers, consultants, researchers, opinion leaders, and journalists). The study also explored collaborative spaces that support internal innovation through interorganisational teams and foster open innovation involving external stakeholders.

Greenwood (2007) examined stakeholders involved in action research processes within higher education. The author identified internal stakeholders (students, academic staff, employees, university centers) and external stakeholders (local communities, employers, trade unions, governments, and government agencies). The study concluded that the engagement of these stakeholders is crucial for the effective implementation and sustainability of action research in academic institutions and for broader societal development. Lloyd-Jones (2020) addressed the challenges faced by university lecturers during the transition from in-person to remote teaching amid the COVID-19 pandemic. The author identified academic staff, administrative personnel, and managerial staff as key stakeholders within the academic institution. These groups participated in and collaborated on efforts to maintain the quality of education.

Tomej and Duedahl (2023) explored stakeholder interactions in the tourism sector aimed at promoting collaboration and accessibility. The identified stakeholder groups included individuals with visual impairments, sighted guides, tourism organisations and enterprises, researchers, and tourism industry experts. The findings suggested that collaboration among these stakeholders can enhance accessibility in tourism. Gurrieri et al. (2018) investigated social marketing and social movements that may collaborate to create inclusive partnerships for social change. The authors identified activists, public health organisations, government entities, and virtual communities as key stakeholders. They argued that existing barriers can be overcome through inclusive partnerships that amplify the voices of diverse stakeholder groups engaged in social movements.

Omma (2024) examined the impact of collaboration among diverse stakeholders on the promotion of regenerative tourism and sustainable, responsible tourism practices. The stakeholder groups included tour guides, tourism service providers, experts, national park staff, cultural center personnel, and volunteers. Each group contributes unique competencies and roles that support the creation of more sustainable tourism experiences. Gibb and Ishaq (2020) addressed decent work as a research tool for assessing job quality and identifying key issues and stakeholders influencing change in this area. The authors emphasised the importance of collaboration among various stakeholder groups in developing strategies that integrate

legislative, social, and organisational dimensions. The identified stakeholders included employees, employers, government organisations, and trade unions.

Shepherd and Ioannides (2020) sought to identify stakeholders involved in INTERREG projects in a selected border region of Norway. The stakeholder groups included local and regional tourism organisations, hotels, museums, pilgrimage centers, and municipalities. Interviews with stakeholders revealed that although EU-funded projects represent a significant source of financing, their structure and operational rules hinder the sustainable development of cross-border tourism. Deslatte and Swann (2020) explored key stakeholders in shaping entrepreneurial orientation and sustainable development efforts in local development contexts. The authors identified representatives of local governments, local communities, politicians, government agencies, enterprises, academic institutions, and non-governmental organisations. Their findings emphasised that effective collaboration among these stakeholders requires trust-building, clear cooperation rules, and resource and knowledge sharing to achieve common sustainability goals.

Townsend et al. (2019) examined a broad spectrum of stakeholders involved in developing a sustainable business model in the fashion industry targeted at mature women. The identified stakeholder groups included mature female consumers, scientists and designers, workshop participants, clothing brands, and research institutions. The study concluded that collaboration among these stakeholders is essential for designing more sustainable and inclusive clothing solutions for this demographic. Fjeldstad et al. (2019) investigated relationships among government agencies in the context of property tax reform in Tanzania, focusing on key stakeholders involved in the process. These included consumers, enterprises, virtual communities, and society at large. The study highlighted challenges stemming from a lack of trust and poor coordination among stakeholder groups, which ultimately hindered the implementation of reforms.

Bettiga et al. (2018) focused on stakeholders associated with virtual co-creation communities. These groups included government entities, local authorities, social enterprises, local communities, organisations supporting social enterprises, and financial institutions (banks, investment funds). The study found that collaboration among these stakeholders is a key condition for creating value for users, enterprises, and society more broadly. Mazzei and Roy (2017) investigated key stakeholder groups in the context of shaping and implementing social enterprise policy in Scotland. The identified stakeholders included government entities, public organisations, project implementers, and consultants. The study noted the diversity of stakeholders and their influence on policy development and implementation, while also acknowledging barriers such as lack of coordination and differences in local approaches.

Ling et al. (2015) analysed the role of key stakeholders in adopting relational contracting practices in public projects in Singapore. The stakeholder groups included government entities, public organisations, project implementers, and consultants. The researchers concluded that collaboration among these groups is critical to the success of public projects. Moreover,

the quality of interorganisational relationships can be enhanced through relational contracting practices, such as mutual trust, information sharing, and joint problem-solving. Alonso et al. (2020) examined stakeholder groups representing the tourism sector in the context of the COVID-19 pandemic and its impact on local communities in a selected region of Argentina. The identified stakeholders included gastronomic enterprises (restaurants, wineries), employees, and local communities, highlighted through job preservation, local economic stabilization, family support, and supplier engagement. The study applied stakeholder theory to identify key challenges, survival strategies, and relationships between enterprises and communities during the crisis.

In response to the research question in the literature reveals a diverse and context-dependent constellation of actors whose involvement reflects both sectoral priorities and societal needs. Educational institutions including universities, schools, and academic staff emerge as central stakeholders across numerous studies. Their participation is often linked to initiatives aimed at developing competencies, fostering innovation, and promoting inclusive pedagogical practices. Students, both as beneficiaries and co-creators, also play a pivotal role, particularly in experiential learning and civic engagement projects.

Public sector entities such as local governments, policy agencies, and public health institutions frequently act as facilitators and coordinators. Their involvement ensures regulatory alignment, resource allocation, and long-term sustainability of collaborative efforts. Private sector stakeholders including SMEs, tech firms, and production managers contribute expertise, infrastructure, and innovation capacity. Their engagement is particularly prominent in lean production environments, cross-functional coordination, and entrepreneurial ecosystems. Social and civic actors such as NGOs, community organisations, and advocacy groups are instrumental in promoting inclusion, reducing stigma, and amplifying marginalized voices. Their participation is often associated with health equity, inclusive tourism, and social justice narratives. Sector-specific stakeholders such as tourism operators, food businesses, and assistive technology designers play a crucial role in tailoring solutions to local and user-specific needs. Their contributions enhance accessibility, cultural sensitivity, and economic resilience, especially in crisis contexts. Finally, collaborative initiatives are shaped by a dynamic interplay of educational, institutional, private, civic, and sectoral stakeholders, each bringing distinct resources, perspectives, and motivations to the table. This diversity is essential for addressing complex challenges through inclusive and context-sensitive approaches.

The research shows that effective stakeholder collaboration across educational, public, private, civic and sector-specific domains is essential for addressing complex societal challenges, fostering innovation and promoting inclusive and sustainable development (Bowser et al., 2024).

Outcomes of collaboration among identified stakeholders

The second of the adopted research questions addressed the reported results of collaboration among stakeholder groups. Based on the literature analysis, a range of outcomes can be identified, demonstrating how joint efforts contribute to the development of competencies, the strengthening of relationships, and the enhancement of effectiveness across various sectors (Table 2).

Table 2.
Identified stakeholder groups

Authors	Outcomes of collaboration among identified stakeholders
Holtzhausen, Botha (2021)	- development of leadership skills in school principals and business leaders, - shift from autocratic to democratic management styles, - strengthening of cross-sector relationships, - increased social awareness and empathy, - improved adaptability in leadership roles.
Kanovska, Tomaskova (2012)	- increased innovation and organisational flexibility, - improved interdepartmental communication, - more effective implementation of changes, - enhanced team-based efficiency, - positive attitude toward teamwork.
Wee (2019)	- better understanding of tourism's role as a social tool, - deeper reflection on space and consumer behaviour, - collaboration with locals and industry experts, - transformative educational experiences for students.
Keahey et al. (2018)	- formation of farmer leadership networks, - enhanced knowledge of certification and market access, - conflict resolution among stakeholders, - strengthening trust and positioning of farmers, - improved communication with industry actors.
Lantz et al. (2015)	- boost in team proactivity in lean production, - establishment of shared meaning of work, - better cross-team collaboration, - increased efficiency and innovation, - strengthening of employee engagement.
Torrens (2017)	- improved design alignment with user needs, - reduced iteration in product development, - increased effectiveness of assistive technologies, - strengthened trust between designers and users, - optimized communication formats for sensory input.
Ungureanu et al. (2020)	- free-flowing knowledge exchange across departments, - mobilization of collective innovation goals, - faster market responsiveness, - support for internal and open innovation, - identification of challenges in collaborative spaces.
Greenwood (2007)	- enhanced quality of action research projects, - creation of participatory learning environments, - engagement with local communities, - promotion of solidarity and mutual learning, - limited impact due to lack of institutional reform.
Lloyd-Jones (2020)	- reduction of students' anxiety during remote learning, - improved handling of technical challenges, - stronger emotional support systems, - creation of educational community bonds, - increased motivation and student participation.

Cont. table 2.

Tomej, Duedahl (2023)	- enhanced accessibility for visually impaired travellers, - building trust between guides and participants, - shared multi-sensory travel experiences, - stereotype reduction through interaction, - greater social inclusion through tourism.
Gurrieri et al. (2018)	- inclusive shift in health campaign language, - supportive and self-accepting relationship building, - reduction in social stigma around body size, - promotion of well-being over illness narratives.
Omma (2024)	- generation of scientific, commercialisable, and follow-up cooperation outcomes, - strengthened science-industry collaboration frameworks, - improved policy design for innovation support.
Gibb, Ishaq (2020)	- enhanced cross-cultural understanding in entrepreneurship education, - development of inclusive pedagogical practices, - strengthening of global entrepreneurial networks.
Shepherd, Ioannides (2020)	- integration of local knowledge into tourism planning, - empowerment of marginalized communities, - improved sustainability through participatory governance.
Deslatte, Swann (2020)	- increased transparency in collaborative governance, - enhanced citizen engagement in urban planning, - strengthened resilience through multi-stakeholder cooperation.
Townsend et al. (2019)	- improved interdisciplinary collaboration in smart city projects, - enhanced data sharing and integration, - strengthened innovation ecosystems.
Fjeldstad et al. (2019)	- development of collaborative public service models, - increased agility in service delivery, - strengthening of trust between public and private actors.
Bettiga et al. (2018)	- improved customer experience through co-creation, - enhanced emotional engagement in service design, - strengthened brand loyalty via participatory innovation.
Mazzei, Roy (2017)	- empowerment of community voices in policy-making, - strengthened legitimacy of collaborative initiatives, - improved responsiveness to local needs.
Ling et al. (2015)	- enhanced coordination in health service delivery, - strengthened inter-agency collaboration, - improved outcomes through integrated care models.
Alonso et al. (2020)	- increased effectiveness of cross-border educational projects, - strengthened intercultural competencies, - enhanced institutional learning through collaboration.

Source: own work.

Holtzhausen and Botha (2019) describe the outcomes of a leadership development program in South Africa that brought together school principals and business leaders. The collaboration led to increased leadership competencies, greater engagement in change processes, improved interpersonal skills, democratisation of management styles, and the building of cross-sectoral relationships. Business partners gained new social perspectives, while school principals received support in navigating challenging educational contexts. Kanovska and Tomaskova (2012) highlight that cross-functional coordination in Czech technology firms yields tangible benefits in terms of increased innovation, flexibility, and organisational efficiency. Interdepartmental collaboration facilitates better resource utilization, a positive attitude toward change, and improved communication and team-based decision-making. Wee (2019) analyses educational travel experiences of Generation Z students, demonstrating how collaboration with

local residents, tourism industry representatives, and academics leads to transformative learning. Students develop social and environmental awareness, gain critical perspectives on tourism infrastructure, and actively participate in redefining tourism as a tool for social engagement. Keahey et al. (2018) document the outcomes of collaboration among rooibos tea farmers, Fairtrade experts, and supporting organisations. Through a participatory approach, networks of local leaders were established, market and certification knowledge was enhanced, and mechanisms for resolving local conflicts were implemented. These joint efforts improved farmers' positions within the industry and enabled long-term development.

Lantz et al. (2015) demonstrate that in lean production systems, team involvement in decision-making and collective learning processes foster employee proactivity and initiative. Collaboration between production and support teams contributes to the creation of shared meaning in work, resulting in greater organisational efficiency and innovation. Torrens (2017), in a study on assistive technology design, illustrates how collaboration between designers, end-users, and healthcare experts enhances product effectiveness. Outcomes include better identification of the needs of individuals with disabilities, reduced design iterations, trust-building, and optimization of sensory communication formats. Ungureanu et al. (2020) discuss the role of collaborative spaces within organisations, where cooperation between cross-functional teams and external stakeholders (e.g., consumers, suppliers) enables faster responses to market changes and mobilization of innovation goals. Collaboration facilitates knowledge exchange and strengthens creativity, although challenges such as process disorder and differing perceptions of innovation spaces may arise. Greenwood (2007) emphasises the importance of collaboration in university education through action research. Outcomes include improved project quality, the creation of participatory environments, and engagement of local communities. However, the lack of sustained institutional support limits the long-term impact of these initiatives on the higher education system.

Lloyd-Jones (2021) describes support initiatives for students during the COVID-19 pandemic, implemented by lecturers through coaching, care, and collaboration. The outcomes included reduced student uncertainty, improved management of technical challenges, enhanced emotional security, and increased engagement in remote learning. The educational relationship evolved into a more supportive and partnership-based dynamic. Tomej and Duedahl (2023) examine collaboration between individuals with visual impairments and sighted guides in the context of inclusive tourism. This relationship fosters greater accessibility to tourism experiences, builds trust, challenges stereotypes, and deepens social awareness. Joint activities enable multisensory exploration of space and strengthen a sense of community. Gurrieri et al. (2018) investigate interactions between fat activism advocates and public health representatives, emphasising that collaboration can transform the language of health campaigns. Instead of medicalized and stigmatizing approaches, communication strategies focused on well-being, supportive relationships, and self-acceptance are developed. The creation of shared narratives leads to more inclusive social practices. Omma (2024)

explores stakeholder engagement in collaborative governance frameworks, emphasising the importance of cross-sectoral cooperation in addressing complex societal challenges. The outcomes include strengthened institutional capacity, improved alignment between public and private actors, and the generation of actionable knowledge for policy innovation. Collaborative forums foster mutual understanding and long-term commitment to shared goals. Gibb and Ishaq (2020) examine entrepreneurship education initiatives involving diverse cultural and institutional stakeholders. Their findings highlight how collaboration enhances inclusive pedagogical practices, supports intercultural dialogue, and builds global entrepreneurial networks. Joint efforts contribute to the development of critical thinking, adaptability, and social responsibility among students.

Shepherd and Ioannides (2020) investigate participatory tourism planning in marginalized communities. Collaboration between local residents, planners, and researchers leads to the integration of indigenous knowledge, empowerment of underrepresented groups, and the co-creation of sustainable tourism models. The process strengthens community agency and fosters long-term resilience. Deslatte and Swann (2020) analyse urban governance projects that rely on multi-stakeholder collaboration. Their study shows that inclusive decision-making improves transparency, enhances citizen trust, and supports adaptive policy responses. Collaborative governance mechanisms contribute to more equitable and responsive urban development strategies. Townsend et al. (2019) focus on smart city initiatives involving public, private, and academic stakeholders. The outcomes of collaboration include improved data integration, enhanced interdisciplinary problem-solving, and the creation of innovation ecosystems. These efforts facilitate more efficient urban services and foster civic engagement in technological development.

Fjeldstad et al. (2019) explore collaborative models in public service delivery. Their research demonstrates that partnerships between government agencies and external actors lead to increased agility, better resource allocation, and strengthened public trust. The co-production of services enhances responsiveness and accountability. Bettiga et al. (2018) investigate co-creation in service design, emphasising emotional engagement between companies and consumers. Collaborative processes result in more personalized experiences, increased customer satisfaction, and stronger brand loyalty. The study highlights the role of empathy and shared value creation in innovation. Mazzei and Roy (2017) examine community-based policymaking through collaborative platforms. Their findings show that inclusive dialogue empowers local voices, enhances legitimacy, and improves responsiveness to community needs. The co-design of policies fosters democratic participation and social cohesion. Ling et al. (2015) analyse integrated care models in health services, where collaboration among providers, patients, and administrators leads to improved coordination, reduced fragmentation, and better health outcomes. Joint planning and shared accountability strengthen system efficiency and patient satisfaction. Alonso et al. (2020) assess cross-border educational projects involving universities, NGOs, and government bodies. The outcomes

include enhanced intercultural competencies, improved institutional learning, and the development of sustainable international partnerships. Collaborative efforts support innovation in curriculum design and student mobility.

Collaboration across stakeholder groups has consistently led to a range of positive outcomes across educational, organisational, technological, and social contexts. First, numerous studies highlight the development of competencies, such as leadership, adaptability, emotional intelligence, and communication skills. For example, Holtzhausen and Botha (2019) found that joint leadership development programs enhanced both school principals' and business leaders' abilities to manage complex environments. Secondly, collaboration contributed to greater effectiveness and proactivity within organisations. Lantz et al. (2015) demonstrated that participatory work design in lean production environments fostered team innovation and initiative. Similarly, Kanovska and Tomaskova (2012) observed that cross-functional coordination in tech firms boosted responsiveness and efficiency. Thirdly, stakeholder partnerships often resulted in stronger social relationships and trust-building. Greenwood (2007) and Wee (2019) illustrate how collaboration between universities, students, and communities deepened civic engagement and experiential learning. Likewise, Tomej and Duedahl (2023) emphasised how interactions between visually impaired tourists and guides promoted inclusion and reduced stigma. Furthermore, several studies reported enhanced accessibility and inclusion, especially in assistive technology design (Torrens, 2017) and inclusive tourism (Tomej, Duedahl, 2023). These partnerships ensured that end-user needs were effectively addressed, improving both design quality and user experience.

In addition, collaborative initiatives contributed to the reduction of marginalisation and stigma. Gurrieri et al. (2018) revealed how joint efforts between public health actors and social movements shifted the narrative from medicalized body discourse to one of well-being and social justice. Moreover, the literature highlights the strategic role of institutional stakeholders, such as local governments, agencies, and funding bodies, in facilitating long-term impact and policy alignment. Deslatte and Swann (2020) and Fjelstad et al. (2019) emphasised how collaborative governance structures enabled more sustainable and scalable solutions, particularly in urban planning and public service delivery.

Another notable outcome was the strengthening of entrepreneurial and innovation ecosystems. Mazzei and Roy (2017) showed that partnerships between universities, SMEs, and incubators fostered knowledge exchange and accelerated the commercialization of research outputs. This was particularly evident in cross-sectoral initiatives involving science parks and regional development agencies. Additionally, the empowerment of local actors, such as smallholder farmers (Keahey et al., 2018) and students navigating remote learning environments (Lloyd-Jones, 2021), was a critical outcome of meaningful, participatory collaboration. These efforts not only improved individual agency but also contributed to broader community resilience.

Finally, stakeholder collaboration in tourism and hospitality sectors, especially during crisis recovery, demonstrated the importance of flexible, inclusive, and culturally sensitive approaches. Alonso et al. (2020) documented how local food businesses and tourism operators adapted through community-driven strategies, reinforcing the social and economic fabric of affected regions. Overall, stakeholder collaboration led to enhanced capabilities, greater social inclusion, improved organisational performance, and the transformation of traditional practices across sectors. These outcomes underscore the value of inclusive and participatory approaches in addressing complex challenges.

4. Conclusions

This article presents a comprehensive bibliometric analysis of stakeholder collaboration, emphasising the identification of stakeholder groups and the outcomes of their cooperative engagements across diverse sectors. Drawing on co-word analysis within the Scopus database, the study systematically examines scholarly literature in the fields of Business and Management. The findings reveal a broad spectrum of stakeholders including educational institutions, business entities, public authorities, civil society organisations, and tourism actors whose interactions contribute to inclusive practices, organisational innovation, and social transformation.

Based on the results, it can be concluded that stakeholders play a crucial role in development, educational, and organisational processes across all sectors analysed. The effectiveness of initiatives undertaken by enterprises often hinges on the proper identification and active engagement of relevant stakeholders. Additionally, cross-sector collaboration has been shown to amplify the impact of activities and reduce social disparities. Strong interpersonal relationships and the exchange of resources underpin effective leadership and foster organisational growth. The article's authors also noted that, in the literature reviewed, stakeholder structures are context-dependent. This indicates that researchers apply various classification schemes (such as internal/external, substantive/contractual, or local/industry/institutional) based on their specific research focus. As a result, there is no universal approach to stakeholder classification; criteria should be tailored to the organisation's specific activities and objectives.

According to the article's authors, collaboration and knowledge exchange among stakeholders foster innovation, learning, and competence development. Notably, external stakeholders can help identify new areas for cooperation, facilitate knowledge transfer, and support proactive organisational behaviours. However, while stakeholder diversity increases management complexity, it also enhances the organisation's developmental potential.

The analysis demonstrates that collaborative efforts among stakeholders generate a wide array of benefits. These include the development of leadership competencies, enhanced cross-functional coordination, the advancement of inclusive tourism and educational models, and the creation of open innovation environments that facilitate knowledge exchange across institutional and sectoral boundaries. Moreover, partnerships between internal and external actors foster mutual learning, resource exchange, and the co-creation of solutions tailored to complex social and organisational challenges. Examples from the literature illustrate how stakeholder engagement cultivates adaptability, emotional resilience, and democratised decision-making.

The study further highlights the strategic value of stakeholder diversity in driving innovation and sustainability. Collaborative networks involving marginalised groups such as smallholder farmers or individuals with disabilities, not only empower these communities but also enrich the design and implementation of policies and technologies. The integration of academic, professional, civic, and experiential perspectives enhances the relevance and impact of collaborative initiatives.

The bibliometric methodology provides a structured lens for tracing the thematic evolution of stakeholder studies and the relational dynamics underpinning cooperation. By mapping keyword co-occurrences and analysing the distribution of stakeholder references, the study uncovers patterns that reflect both disciplinary convergence and contextual specificity. These insights deepen our understanding of stakeholder collaboration as a mechanism for capacity building, social inclusion, and systemic change. Importantly, the findings resonate with the principles of the knowledge-based economy, where value creation increasingly depends on intellectual capital, cross-sectoral partnerships, and the mobilization of diverse knowledge sources. Stakeholder collaboration emerges not only as a tool for solving complex problems but also as a driver of innovation ecosystems, institutional learning, and adaptive governance. In this context, fostering inclusive, reflexive, and context-sensitive stakeholder relationships becomes essential for sustainable development and organisational resilience.

In conclusion, the article underscores the transformative potential of stakeholder engagement in contemporary organisational and societal settings. It calls for further inquiry into the mechanisms that enable effective collaboration, the barriers to equitable participation, and the long-term outcomes of stakeholder-driven initiatives in an increasingly interconnected world.

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EPIDEMIC SEIR MODEL OF THE E-COMMERCE CUSTOMER LIFE-CYCLE FOR DEMAND ESTIMATION UNDER TIME-VARYING MARKETING EXPENDITURES AND SEASONAL EFFECTS

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Purpose: This paper develops a weekly e-commerce demand model that explicitly captures exposure, activation, churn, and reactivation in the customer life-cycle during purchasing process dynamics under time-varying marketing pressure and seasonality.

Design/methodology/approach: Using three years of weekly transaction data from an online retailer, along with real marketing expenses and seasonal effects, we calibrate a latent-state-space SEIRS model of the customer life-cycle in the purchasing process. We introduce a time-varying transmission parameter that aggregates marketing pressure, social influence, and seasonality, while separate transitions between customer states capture customer churn and reactivation.

Findings: The SEIRS model outperforms the SARIMA benchmark in test-window forecasts and provides interpretable diagnostics, including transition paths between customer states and a demand indicator derived from the difference between active and outgoing customers. Scenario analysis shows that different customer churn and reactivation rates generate different demand trajectories.

Research limitations/implications: Models of individual state spaces, inspired by epidemiology, can be used for marketing purposes by separating exposure, conversion, and flow processes across states in the life cycle, offering more diagnostic possibilities than standard time-series models.

Practical implications: The model's parameters reflect factors influencing demand and conversion dynamics in the purchasing process. Monitoring the transmission parameter λ_t , the momentum proxy R_t , and the churn and reactivation parameters (γ, ω) support coordination of marketing expenditures and seasonal revenues. For managers for whom demand forecasting is a key issue, it may also be helpful to identify the customer life-cycle mechanisms that drive demand changes: customer acquisition, customer churn, and customer reactivation. Without understanding these mechanisms, general principles form the basis for campaign budgets, which risks overspending during periods of low demand and underinvestment when conditions are favorable for recovery.

Originality/value: The paper proposes a compact life-cycle specification of the customer life-cycle in the purchasing process, that treats churn and reactivation as explicit, estimable state transitions in a weekly demand system, combining strong forecasting with operational interpretability.

Keywords: Marketing analytics; E-commerce demand; State-space modeling; Decision support.

Category of the paper: Research paper.

1. Introduction

E-commerce demand is rarely stable. Many retailers see sudden surges followed by stable periods, slowdowns, and renewed activity, driven by social influence, marketing, and calendar-based seasonality. From a marketing analytics view, this reflects a recurring customer life-cycle: consumers become aware and active, some churn, and many later return through reactivation rather than only through first-time adoption. Yet classical diffusion models, such as the Bass model (Bass, 1969), focus on cumulative adoption of new products via innovators and imitators and do not explicitly model exposure, dropouts, or reactivation (Peres et al., 2010; Rogers, 2003). This limits their value for managers who need measurable signals to predict customer churn and plan reactivation. In practice, churn analytics is often framed as a predictive classification task, but recent work highlights the importance of time-to-event structure and explainability when churn signals guide the timing of retention interventions (Dias, Antonio, 2025; Kimitei et al., 2025).

To capture these stages in the customer life-cycle in e-commerce processes, we use compartmental diffusion models (SIR/SEIR/SEIRS) that explicitly represent exposure, delayed activation, loss of activity, and possible market reentry (Kermack, McKendrick, 1927; Medrek, Pastuszak, 2021; Tillett, 1992). Originally developed for epidemiology, these models are now widely applied to digital behavior and adoption, where awareness and engagement spread via social contact and information exchange (Fibich, 2016a; McAdams, Song, 2025). Related work proposes hybrid diffusion–epidemic models, such as Bass–SIR variants, to capture periods of limited customer influence and subsequent inactivity (Peres et al., 2010). Empirical and simulation studies in online settings likewise show that the path from exposure to activity can mirror the transition from awareness to purchase in e-commerce (Woo, Chen, 2016). These findings point to models that track exposure, activation, churn, and reactivation of customers as distinct stages rather than components of fixed curves. Customer analytics is increasingly used to anticipate churn and proactively optimise commercial actions (Wolniak, 2024), aligning with the use of latent-state dynamics as early-warning signals for intervention timing.

Although customer marketing analytics applications are very promising, significant challenges remain. One such example is the difficulty of accurately attributing changes in demand to internal feedback or external marketing pressure, as both evolve and their impacts are interconnected. Additionally, using a reproduction number outside of epidemiology is controversial. If used, it must be consistently defined and estimated from available data to avoid

misleading interpretations (Nash et al., 2022). These issues require a framework that links time-dependent demand to marketing and calendar inputs while keeping customer life-cycle stages (e.g., churn and reactivation) explicit and estimable.

This paper models weekly e-commerce demand using a latent-state SEIRS framework that explicitly represents stages in the customer life-cycle, i.e., exposure, activation, churn, and reactivation under time-varying transmission between stages, driven by social, marketing, and calendar effects. By linking latent dynamics to real store data, the method gives metrics $(\lambda_t, \gamma, \omega)$ and a reproduction proxy that we use as a demand signal. We test the model's validity by comparing conversion forecasts to a seasonal time-series benchmark SARIMA. Our work is both theoretical and practical. We demonstrate the life-cycle forces driving demand and provide a tool for managing seasonal demand through marketing pressure.

We test the proposed approach through four research hypotheses.

H1: The epidemic customer life cycle model improves e-commerce demand forecasts compared to the standard benchmark.

H2: The SEIR model provides early warning signals in e-commerce management.

H3: Customer loss and reactivation mechanisms influence demand trajectories.

H4: The SEIRS model provides an interpretable indicator, akin to the epidemic reproduction number, that identifies expansive and recessive configurations of e-commerce systems in terms of order numbers.

The paper is organised as follows. Section 2 provides a literature review, discusses new product adoption, diffusion, and compartmental approaches, and motivates the extension of the customer reactivation stage through modelling. Section 3 presents the model specification, calibration, and case data. Section 4 reports forecasting performance, diagnostics, and sensitivity scenario analyses, and Section 5 concludes with managerial implications, limitations, and directions for further work.

2. Literature review: customer life-cycle dynamics in e-commerce demand

In this part of our work, we place the proposed SEIRS model of customer life cycle states in the e-commerce purchasing process within two strands of marketing analytics research: diffusion models explaining long-term penetration (people who always use a given service) and offer contagion models based on stages of exposure, customer activation, and influence decay. The primary motivation is that demand in e-commerce is shaped not only by one-time acceptance of an offer, but also by the recurring dynamics of the customer life cycle: temporary inactivity (churn) and return (reactivation/recovery). Section 2.1 discusses Bass's model and explains why cumulative penetration is insufficient for modeling real demand. Section 2.2 summarizes SEIR network diffusion models and their ability to represent stage-based activation

with limited impact. Section 2.3 identifies a gap in SEIR models for e-commerce demand and justifies a minimal extension of SEIRS models to include a customer reactivation to the initial stage. The final section (Section 2.4) presents the design requirements for state space models such as the proposed SEIRS model.

2.1. Bass diffusion for penetration

The Bass model remains a reliable tool for modeling the timing of the initial adoption of new products. It assumes that the probability of purchase at time t is linearly related to the cumulative number of previous adopters, capturing two mechanisms: innovation (external influence) and imitation (internal influence) (Bass, 1969). This behavioral premise yields an adoption-rate curve that rises to a single peak and then decays as the market saturates.

Formally, the adoption rate $f(t)$ and the cumulative share of adopters $F(t)$ follow

$$f(t) = \frac{dF(t)}{dt} = (p + qF(t))[1 - F(t)] \quad (1)$$

and

$$F(t) = \frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p}e^{-(p+q)t}} \quad (2)$$

where p is the coefficient of innovation and q the coefficient of imitation (Bass, 1969). Figure 1 illustrates the characteristic S-shaped cumulative diffusion and its corresponding adoption-rate peak.

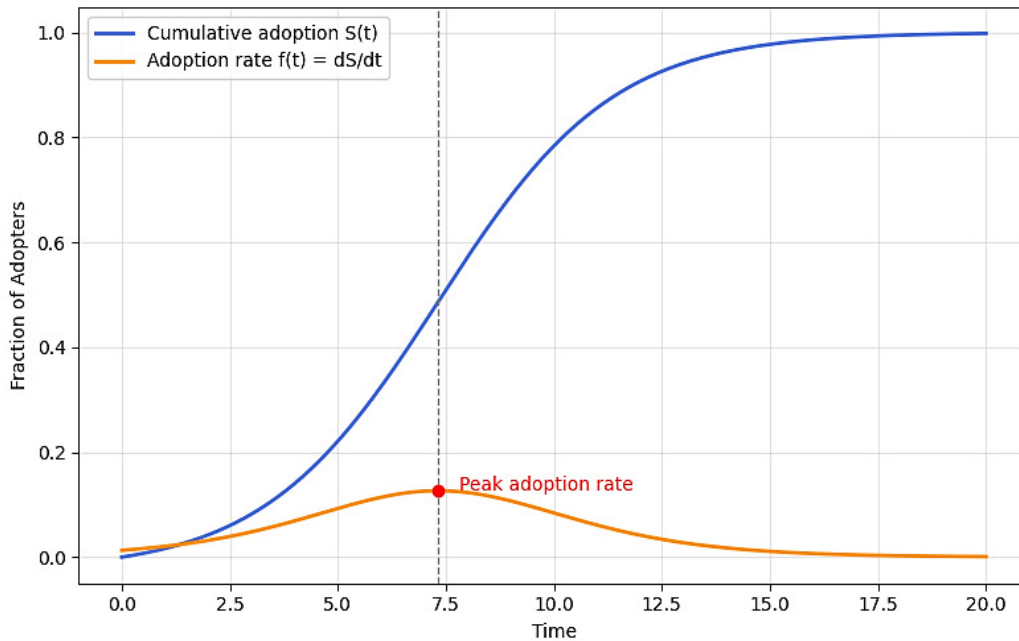


Figure 1. Traditional Bass diffusion model (Bass, 1969). The blue line $S(t)$ is the cumulative adoption share, forming an S-curve that starts slowly, speeds up through imitation, and then nears saturation. The orange curve $f(t) = dS/dt$ is the adoption rate, peaking when innovation and imitation balance; the red point marks the maximum adoption intensity.

Although empirically successful in modeling innovation penetration, the Bass model is structurally misaligned with recurring demand in digital retail. It assumes a homogeneous population, ignores the structure of the social network and its heterogeneous influence, and treats market potential as fixed, with a one-way transition to adoption, which is reasonable for "ever-adopters" but not for actual consumer behavior, where customers cycle in and out. The model also omits repeat purchases and reactivation, making it unsuitable for the cyclical buying and return patterns typical of modern e-commerce. Finally, it does not explicitly capture external shocks, such as marketing expenditures, social influence (media word of mouth effect), or macroeconomic changes, that can strongly affect diffusion in real digital markets (Peres et al., 2010; Rogers, 2003). In terms of marketing analytics, Bass explains the cumulative penetration¹ rather than the active customer base that generates weekly orders.

2.2. SEIR models for staged adoption

To model staged behavioral dynamics, diffusion studies in social systems increasingly use SIR/SEIR compartmental frameworks. In these approaches, consumers move from susceptible (S ; reachable but not yet influenced), through exposed (E ; aware/considering) and active/infectious (I ; purchasing and potentially influencing others), and finally to removed (R ; no longer influencing) (Kermack, McKendrick, 1927; Medrek, Pastuszak, 2021b; Tillett, 1992). In discrete time, a standard SEIR update in a closed population $N = S_t + E_t + I_t + R_t$ can be written as

$$\begin{aligned} S_{t+1} &= S_t - \beta \frac{S_t I_t}{N}, \\ E_{t+1} &= E_t + \beta \frac{S_t I_t}{N} - \sigma E_t, \\ I_{t+1} &= I_t + \sigma E_t - \gamma I_t, \\ R_{t+1} &= R_t + \gamma I_t, \end{aligned} \tag{3}$$

where β is the transmission intensity, σ the exposure to activation conversion, and γ the rate at which influence/activity decays.

A key advantage of such interpretations is that transmission depends on who interacts with whom: exposure risk rises with neighbour activity, and diffusion speed becomes sensitive to local structure rather than a single aggregate path (Prashad, 2025). This aligns with marketing evidence that awareness and adoption spread through word of mouth (WOM), information exchange, and belief updating (McAdams, Song, 2025; Woo, Chen, 2016). Hybrid diffusion–contagion models (e.g., Bass–SIR variants) formalise finite influence windows and subsequent inactivity, improving realism of the modelled life-cycle when attention decays quickly (Peres et al., 2010). SEIR-type models further separate exposure formation, delayed conversion,

¹ Penetration is the number of unique users who have adopted at least once; it does not necessarily reflect current activity.

and influence decay, and naturally model time-varying transmission to reflect a changing market context.

2.3. Customer churn and reactivation as fundamental modeling primitives: an SEIRS-based extension

Repeated purchases and recurring engagement drive weekly e-commerce demand. Customers cycle through awareness and purchase, then become inactive, and later return via seasonal revisits, campaign-driven comebacks, or renewed interest after assortment or price changes. Classical diffusion models emphasize long-term penetration and omit churn and reactivation, while standard SEIR models assume removed users never return, which is inconsistent with the dynamics of customer recovery (Fibich, 2016b; Nash et al., 2022; Papageorgiou, Tsaklidis, 2023). Modeling these dynamics requires an explicit loop from the inactivity stage back to the susceptibility stage.

We therefore adopt the SEIR extension that introduces reactivation, i.e., SEIRS. In discrete time, we interpret compartments as: Susceptible (S_t ; able to buy but not purchasing this week), Exposed (E_t ; aware/considering), Active (I_t ; purchased this week), and Removed (R_t ; temporarily inactive). Reactivation is implemented as a return flow $R \rightarrow S$ governed by $\omega \in (0,1)$:

$$\begin{aligned} S_{t+1} &= S_t - \lambda_t S_t + \omega R_t, \\ E_{t+1} &= E_t + \lambda_t S_t - \sigma E_t, \\ I_{t+1} &= I_t + \sigma E_t - \gamma I_t, \\ R_{t+1} &= R_t + \gamma I_t - \omega R_t \end{aligned} \quad (4)$$

where λ_t is time-dependent transmission intensity ($S \rightarrow E$), σ is conversion ($E \rightarrow I$), and γ is churn ($I \rightarrow R$). Figure 2 summarizes the resulting looped life-cycle mechanism.

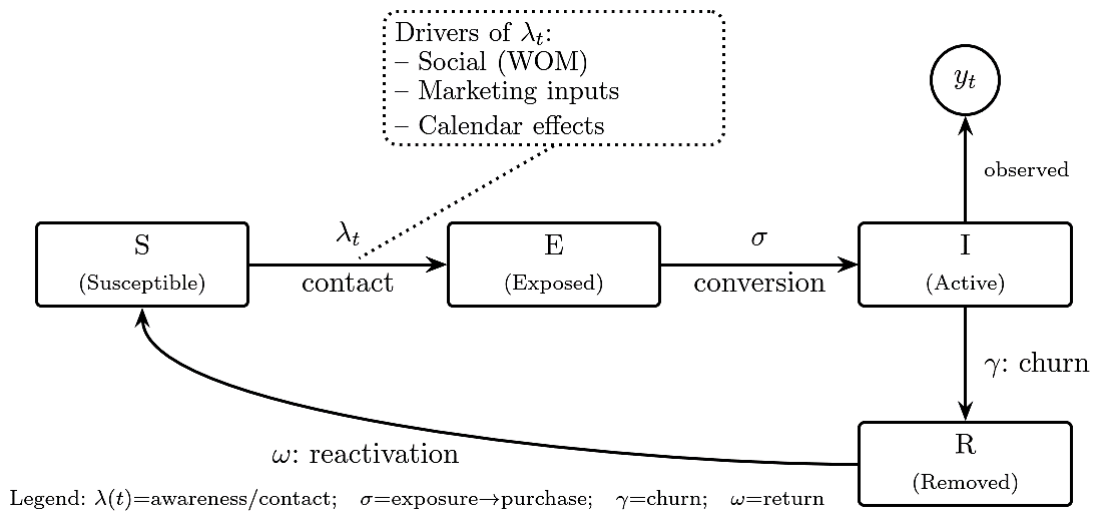


Figure 2. SEIRS transition diagram for e-commerce with observed output y_t and drivers λ_t . Arrows denote flows between states S, E, I, R, S in time step t .

In marketing analytics, it is crucial that the parameter λ_t must vary over time and aggregate multiple factors. The social diffusion of demand depends on the structure of the network and the decay of attention (McAdams, Song, 2025; Prashad, 2025), the belief updates shape the demand in the adoption epidemic models (Woo, Chen, 2016), and in digital commerce the effects of paid media and calendars can influence the exposure to offers and the intentions of potential customers. We therefore model λ_t as a time-varying intensity driven by internal WOM/social activity, external marketing inputs, and calendar/exogenous shocks. The reactivation loop offers two practical benefits. Primarily, it explains repeated waves of customer activity: peaks can be driven by increased conversion (σ) and/or by a larger customer reactivation inflow (ω) that replenishes the susceptible pool available for conversion. It also provides a breakdown of demand dynamics into transmission and departures of customers, and the SEIRS structure allows for a consistent mapping between estimated values of λ_t , γ , and the persistence of customer activity.

2.4. Design requirements for an interpretable state-space demand model

The literature identifies three design needs for an e-commerce demand model that supports marketing decisions. Initially, the model should go beyond total reach to incorporate stage trends (exposure and activation) and life-cycle flows (churn and reactivation). Second, transmission must be time-varying and interpretable, distinguishing endogenous social effects from exogenous marketing and calendar drivers (Rogers, 2003). Lastly, any reproduction-style indicator must be derived from the same model used to estimate transmission and be consistent with the measurement scale (Nash et al., 2022; Papageorgiou, Tsaklidis, 2023).

Guided by these requirements, we operationalise a state-space SEIRS model that treats exposure, churn, and customer reactivation as state transitions between stages of the customer life-cycle. We link the latent states to store-level measurements and optimise the model's parameters using weekly observations. The state equations describe the latent dynamics and map activity to orders. The model also integrates weekly observations into forecasting: it explains why forecasts deviate around turning points by attributing changes to transmission (marketing/social/calendar), churn, and reactivation mechanisms. Thus, the approach extends diffusion-style thinking toward repeat purchase and win-back dynamics, which are central to e-commerce demand management.

3. Methods

In this section, we start with the model specification, including state dynamics, transmission, the observation equation, and a demand-momentum indicator. Then, we describe calibration and initialization, followed by the case data source and construction of marketing and seasonal drivers.

3.1. Numerical model

3.1.1. State variables and transition dynamics

We model weekly customer dynamics with a latent state vector $X_t = (S_t, E_t, I_t, R_t)$, partitioning addressable customers into Susceptible (S_t , able to buy but not purchasing this week), Exposed (E_t , aware or considering), Active (I_t , at least one purchase this week), and Removed (R_t , temporarily inactive). In the closed-population case,

$$N = S_t + E_t + I_t + R_t = \text{const}, \quad (5)$$

with all non-zero components, $S_t, E_t, I_t, R_t > 0$.

To accommodate slow changes in the reachable base (e.g., net sign-ups, market expansion), we allow an external net flow b_t into S_t . The weekly SEIRS updates become

$$\begin{aligned} S_{t+1} &= S_t - \lambda_t S_t + \omega R_t + b_t \\ E_{t+1} &= E_t + \lambda_t S_t - \sigma E_t \\ I_{t+1} &= I_t + \sigma E_t - \gamma I_t \\ R_{t+1} &= R_t + \gamma I_t - \omega R_t, \end{aligned} \quad (6)$$

and the total population evolves as

$$N_{t+1} = N_t + b_t. \quad (7)$$

We restrict b_t to be small relative to N_t to avoid confounding slow base drift with the exposure process governed by λ_t . Transition rates are weekly probabilities: churn $I \rightarrow R$ is $\gamma \in (0,1)$ and reactivation $R \rightarrow S$ is $\omega \in (0,1)$.

3.1.2. Time-varying transmission with marketing and calendar drivers

To reflect social influence, paid marketing inputs, and calendar/external effects, we model the transmission intensity as a bounded, time-varying quantity:

$$\lambda_t = \frac{1}{1 + \exp(-\eta_t)}, \quad (8)$$

$$\eta_t = \beta_0 + \beta_1 \left[\left(\frac{I_t}{N_t} \right)^\alpha - \left(\frac{I}{N} \right)^\alpha \right] + \delta \tilde{M}_t + \theta Z_t, \quad (9)$$

where β_0 captures the baseline exposure tendency, and the centered term $(\frac{I_t}{N_t})^\alpha - \overline{(\frac{I}{N})}^\alpha$ captures endogenous social dependence: higher activity shares increase the chance that susceptible individuals are exposed. The bar denotes the training window mean of $(\frac{I_t}{N_t})^\alpha$, so that β_0 retains the interpretation of typical baseline exposure when deviations in social activity, marketing, and seasonality are absent.

The exponent $\alpha > 0$ allows a flexible nonlinear response:

$$\alpha = \begin{cases} 1 & \text{linear in the active share,} \\ > 1 & \text{threshold-like (weak at low activity, strong once activity is high),} \\ < 1 & \text{diminishing returns (strong early, then saturates).} \end{cases} \quad (10)$$

Marketing influence is represented by $\delta \tilde{M}_t$, where M_t may include marketing expenses (e.g., email volume or paid promotion). Positive values increase exposure, while negative weights reflect poor targeting or adverse effects. Calendar/external effects (holidays, paydays, seasonality proxies, logistics shocks) enter via θZ_t . All inputs are centered so that β_0 still corresponds to the typical weekly baseline when marketing and seasonal deviations are absent.

3.1.3. Observation equation and demand-momentum indicator

The observed weekly e-commerce outcome (orders, active buyers, or revenue) is linked to the latent active state through

$$y_t = \kappa \cdot I_t + \epsilon_t, \quad (11)$$

where $\epsilon_t \sim \mathcal{N}(0, \sigma_\epsilon^2)$ and κ is the outcome scaling parameter (see Table 1).

We define a reproduction style demand-momentum proxy as

$$\mathfrak{R}_t = \frac{\lambda_t}{\gamma}, \quad (12)$$

where λ_t is the intensity of the weekly transformation $S \rightarrow E$, and γ is the weekly churn rate $I \rightarrow R$. Values $\mathfrak{R}_t > 1$ indicate self-sustaining demand in the absence of additional lift, while $\mathfrak{R}_t < 1$ signals decay unless marketing or seasonality increases the transmission intensity λ_t .

3.2. Model calibration

We calibrate the model using weekly retailer data: target y_t (number of orders), marketing input M_t (paid exposure proxy), and calendar/seasonality driver Z_t . The time step equals one week. The parameter vector is

$$\Theta = \{\beta_0, \beta_1, \alpha, \delta, \theta, \sigma, \gamma, \omega, \kappa, \sigma_\epsilon\}. \quad (13)$$

Latent states follow

$$X_t = (S_t, E_t, I_t, R_t), \quad (14)$$

with mass balance given by eq.(5). We set the initial reachable population to N_0 , corresponding to the number of customers that can be reached at t_0 . In our case, N_0 is set to the 52-week unique visitors to the store website, which is observable and sufficiently stable for weekly

dynamics, and consistent with the observation equation (11) where κ absorbs purchase intensity. To reflect the increase in exposure, we set the initial value of E_0 to small part of N_0 . Then, based on the initial observation, the activity I_0 is determined. Similarly, we can infer recent inactivity and close the mass as follows

$$\begin{aligned} E_0 &= \varepsilon_E \cdot N_0, (\varepsilon_E \ll 1), \\ I_0 &\approx \frac{y_0}{\kappa}, \\ R_0 &= \rho_R \cdot N_0, \\ S_0 &= N_0 - E_0 - I_0 - R_0, \end{aligned} \tag{15}$$

where ρ_R reflects the initial share of lapsed but reachable customers.

Initial values of transition rates σ, γ, ω are set within economically plausible ranges (e.g., σ^{-1} about 1–2 weeks, γ^{-1} a few weeks, and ω^{-1} aligned with seasonal revisit horizons), and the final estimates are obtained by minimizing RMSE on the training window with boundary constraints $0 < \sigma, \gamma, \omega < 1$. Transmission parameters $(\beta_0, \beta_1, \alpha, \delta, \theta)$ are estimated via eqs. (8)-(9) to align λ_t with observed turning points while avoiding overfitting of state dynamics. The scale parameter κ is estimated from the regression of y_t on I_t for the selected λ_t , and σ_ϵ is set to the standard deviation of the residuals.

Parameter estimation was performed using constrained, gradient-based optimisation on the training window, with initial conditions selected to ensure stable state trajectories. To support reproducibility, the complete parametrisation (bounds, initialisation, and driver transformations) can be provided upon reasonable request; the underlying retailer-level dataset is proprietary.

3.3. Case data and driver construction

The empirical analysis uses weekly transaction and exposure data from a medium-sized Polish online retailer specialising in gardening and construction tools. The dataset covers three years (from early 2023) and includes weekly orders y_t , paid marketing expenditure M_t (Google Ads), and calendar-based seasonal indicators Z_t .

Figure 3 shows the weekly orders series used for training (grey) and testing (black). Peaks correspond to periods of intensified paid exposure and/or seasonal triggers.

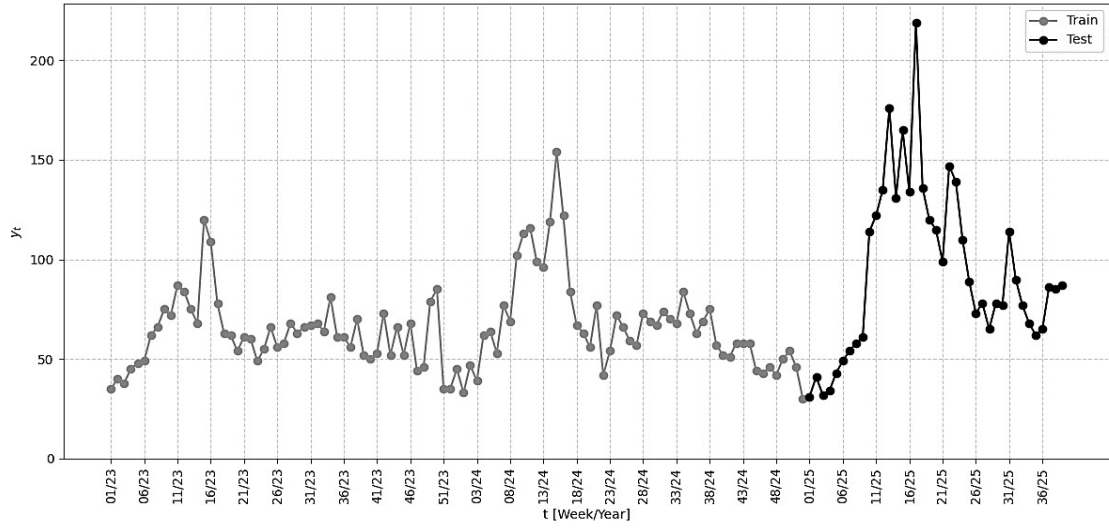


Figure 3. Weekly observed number of orders y_t representing active demand dynamics used for SEIRS model training and calibration (gray line) and testing (black line).

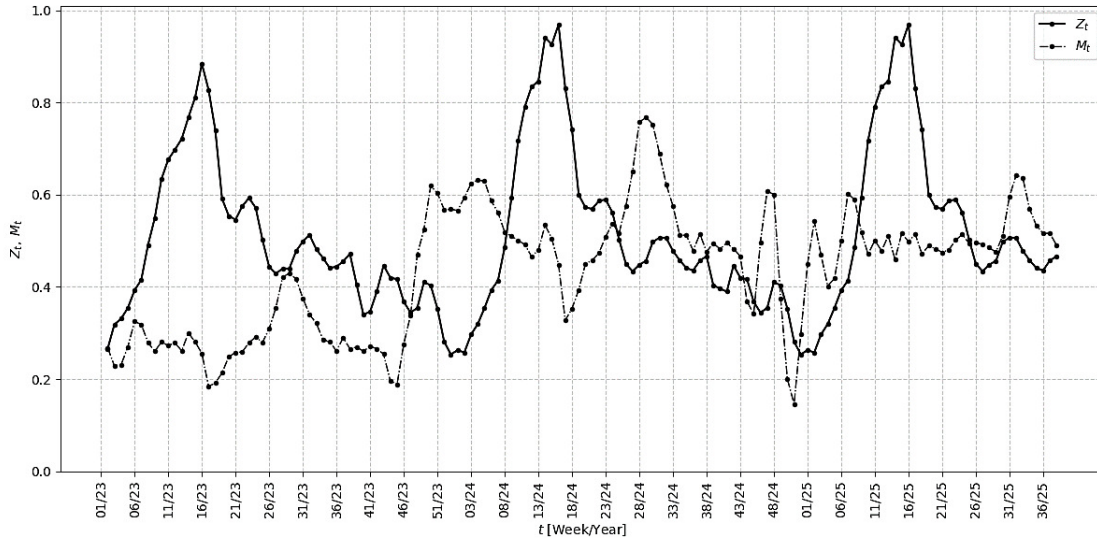


Figure 4. Time-varying marketing M_t and seasonal drivers Z_t of transmission intensity λ_t . Normalized Google Ads spend M_t is denoted by dash-dot line, and the seasonal calendar effect Z_t is marked with a solid line.

Figure 4 shows the time-varying marketing and seasonal drivers used to modulate λ_t in eqs. (8-9). Seasonality is estimated using a ratio-to-trend approach: a smooth trend T_t is obtained via a symmetric moving average ($n_t = 16$ weeks), and a raw seasonal multiplier is computed as $s_t = y_t/T_t$. To include seasonality additively in the linear predictor, we center the seasonal index:

$$Z_t = s_t - \bar{s}, \quad \bar{s} = \frac{1}{n} \sum_{t=1}^{n_t} s_t. \quad (16)$$

The marketing driver, whose value corresponds to weekly marketing expenditures, is centered analogously, $\tilde{M}_t = M_t - \bar{M}$, so that β_0 represents the baseline exposure tendency when marketing and seasonal deviations are absent. Such centering stabilizes identification when decomposing transmission into social, marketing, and calendar components.

Table 1 reports the final estimates of the parameter vector Θ defined in eq. (13). All external drivers (marketing and seasonality) were first transformed (smoothed over time if necessary). Parameters were then fitted on the training window using a gradient-based procedure with boundary constraints, minimizing RMSE.

With centered drivers, the baseline of the linear predictor η_t is set by the intercept $\beta_0 = -0.817$, implying a baseline weekly transmission of

$$\lambda = \text{logit}^{-1}(\beta_0) = \text{logit}^{-1}(-0.817) = 0.306. \quad (17)$$

The social component is strong but operates on a small-scale driver: $\beta_1 = 9.255$ and $\alpha = 0.960$ imply that $\beta_1(I_t/N)^\alpha$ increases rapidly even at low activity shares, generating sizeable changes in η_t (and thus λ_t) when I_t/N rises from about 1-3% to 5-8%. Marketing and seasonality inputs enter through centered (and, where appropriate, standardised) regressors, which preserves an interpretation of β_0 as the typical baseline exposure tendency.

Table 1.

Calibrated parameters, components of Θ described by eq.(13)

Symbol	Interpretation	Estimate
β_0	Baseline exposure tendency in the linear predictor η_t	$-8.1720e - 01$
β_1	Strength of social influence on $(I_t/N)^\alpha$	$9.2548e + 00$
α	Nonlinearity of social influence	$9.6000e - 01$
δ	Weights on effective marketing input $\mathbf{M}_{nM}$	$6.9000e - 01$
θ	Weights on seasonal/exogenous drivers $\mathbf{Z}_{nZ}$	$3.4400e + 00$
σ	Exposure→active conversion rate ($E \rightarrow I$) per week	$8.0000e - 01$
γ	Churn ($I \rightarrow R$) per week	$4.6100e - 01$
ω	Reactivation ($R \rightarrow S$) per week	$2.6700e - 01$
κ	Per-active output scaling in $y_t = \kappa I_t + \varepsilon_t$	$1.0000e + 02$
σ_ε	Observation noise standard deviation in $y_t = \kappa I_t + \varepsilon_t$, $\varepsilon_t \sim N(0, \sigma_\varepsilon^2)$	$1.4000e + 01$

Transition rates are weekly: $\sigma = 0.80$ implies an average exposure to active time of $1/\sigma \approx 1.25$ weeks, $\gamma = 0.461$ implies an average active duration of $1/\gamma \approx 2.17$ weeks, and $\omega = 0.267$ implies an average return to susceptible time of $1/\omega \approx 3.75$ weeks, consistent with monthly revisit patterns.

4. Results, diagnostics, and comparative performance

This section evaluates the empirical performance of the state-space SEIRS model using a test window not used during training. We present forecasts, residual diagnostics, and behavioral interpretability via inferred latent states and dynamic indicators. These include

the time-varying transmission intensity λ_t and the demand-momentum proxy $\mathfrak{R}_t$. Additionally, we summarize a sensitivity analysis to assess the impact of uncertainty in key parameters on forecasting accuracy. Overall, our objective is to demonstrate that the proposed life-cycle representation enhances short-term prediction and provides a transparent decomposition of demand into exposure, activation, churn, and reactivation mechanisms that managers can interpret.

4.1. Forecast accuracy SEIRS vs. SARIMA

Figure 5 compares weekly orders y_t predicted by the SEIRS model (red) and a SARIMA benchmark (blue) against the observed number of orders (black). The vertical line marks the start of the test window (the beginning of 2025). For readability, the plots in this section are restricted to the last two years of the sample. The figure shows that SEIRS tracks turning points earlier and reproduces peak amplitudes more closely than SARIMA. This advantage stems from the model's time-varying transmission λ_t , which is explicitly modulated by paid marketing inputs and calendar effects (Figure 4), whereas SARIMA captures seasonality through an autoregressive structure alone.

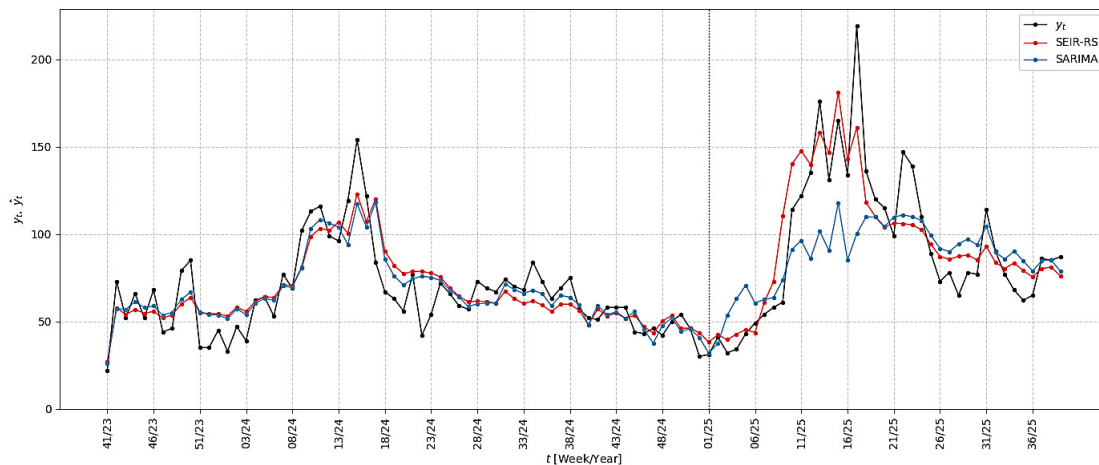


Figure 5. Observed weekly orders y_t (black) and forecasts from SEIRS (red) and SARIMA (blue). The vertical line marks the start of the test window (2025).

Table 2 summarises forecast errors on the test window. SEIRS improves all metrics relative to SARIMA: RMSE decreases by 14.4% ($22.34 \rightarrow 19.12$), MAE by 15.9% ($18.21 \rightarrow 15.32$), and MAPE by 33.3% ($18.21\% \rightarrow 12.14\%$). The gains are most visible around local extrema (peaks and troughs), where SEIRS better captures changes in exposure and subsequent activation rather than extrapolating past levels. These results suggest that including latent life-cycle stages and varying transition strengths can yield more accurate short-term forecasts than a basic autoregressive seasonal model.

Table 2.

Comparison of forecast quality for SEIRS model and SARIMA in the test window (Figures 5, 6, $t \in (01/25, 40/25)$; time step = 1 week)

Model	RMSE	MAE	MAPE
SEIRS	19.12	15.32	12.14%
SARIMA	22.34	18.21	18.21%

Figure 6 reports test-window residuals $e_t = y_t - \hat{y}_t$ for both models. SEIRS residuals cluster closer to zero with less apparent serial structure, while SARIMA exhibits larger errors around abrupt changes. The distributions are approximately symmetric, with occasional positive spikes consistent with short-lived shocks that neither method fully captures.

Figure 7 complements residual analysis with residual autocorrelation. For SEIRS (panel (a)), most $ACF(e_t)$ values lie within the 95% bounds, indicating limited remaining serial dependence after accounting for exposure–activation dynamics. For SARIMA (panel (b)), residual dependence persists beyond short lags, suggesting unmodelled structure related to latent behavioral transitions.

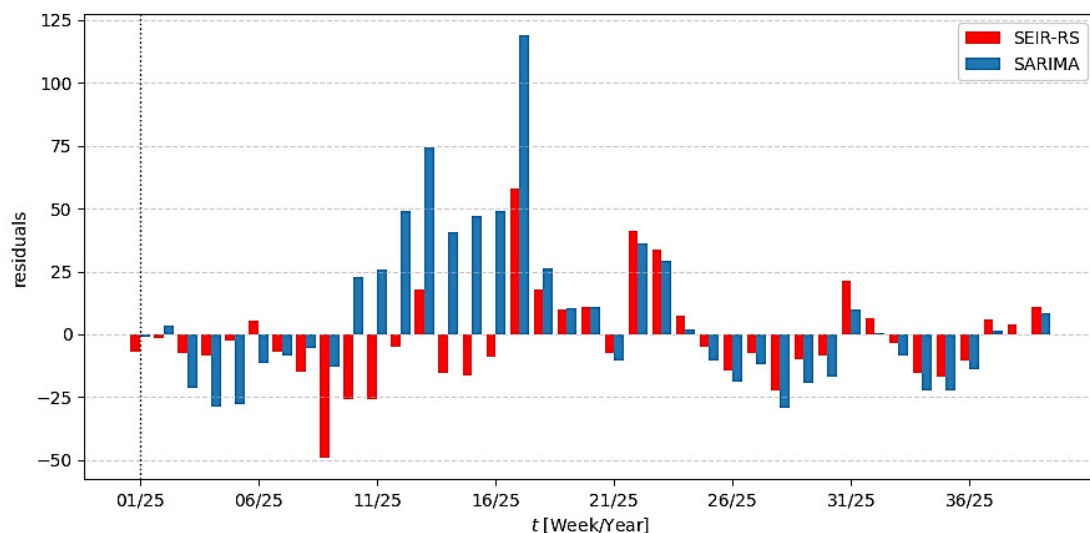


Figure 6. Test-window forecast residuals $e_t = y_t - \hat{y}_t$ for SEIRS (red) and SARIMA (blue).

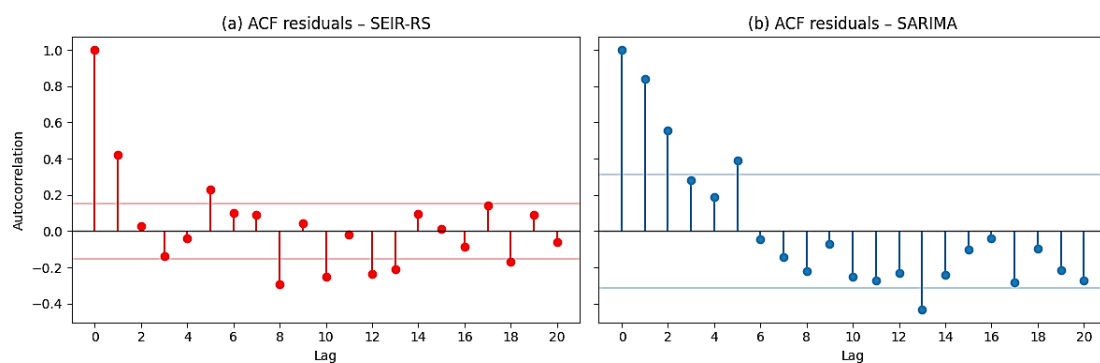


Figure 7. Residual autocorrelation $ACF(e_t)$ on the test window for (a) SEIRS and (b) SARIMA; the lighter lines indicate 95% confidence bounds.

4.2. SEIRS dynamics of the latent variables

Beyond forecasts, latent states provide a behavioral explanation of demand cycles. In particular, the trajectories of I_t (active) and R_t (temporarily inactive) individuals turn a black-box prediction into a life-cycle diagnosis by separating exposure effects from conversion and churn. The transmission factor λ_t acts as an early signal: it tends to rise before surges in activity and to recede after peaks, enabling diagnostic interpretation of interventions and seasonal shifts.

Figure 8 shows the latent compartments and transmission. The active state I_t co-moves with observed orders through the observation eq. (11). Importantly, increases in λ_t typically precede increases in I_t , consistent with a lead-lag mechanism in which shocks first affect exposure (via λ_t) and then translate into purchases through conversion σ . Together, the trajectories support interpreting demand peaks and lulls as the balance of transmission, churn γ , and reactivation ω under marketing and calendar modulation.

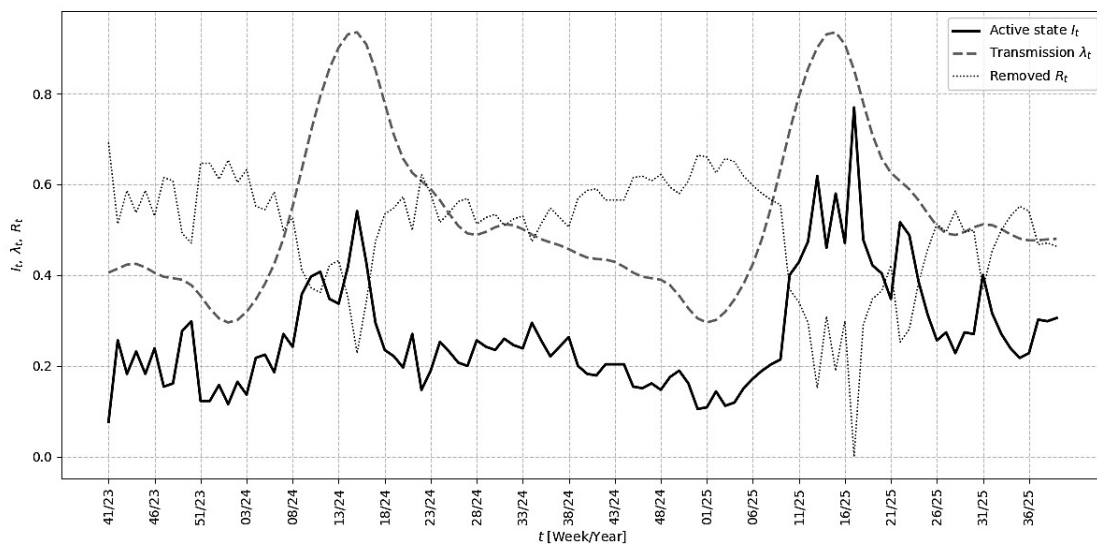


Figure 8. Inferred latent states and transmission for the SEIRS model: active buyers I_t , removed (inactive) state R_t as parts of N_0 , and time-varying transmission λ_t over the training and test windows.

Figure 9 reports the demand momentum proxy $\mathfrak{R}_t = \lambda_t/\gamma$, with the horizontal reference line at $\mathfrak{R}_t = 1$. Periods with $\mathfrak{R}_t > 1$ indicate conditions under which exposure inflows are sufficient to offset churn, and they typically precede demand expansions. Conversely, sustained periods with $\mathfrak{R}_t < 1$ signal weakening demand and are associated with slowdowns unless marketing or seasonal factors lift λ_t . Interpreting $\mathfrak{R}_t$ jointly with Figure 8 helps distinguish peaks driven by propagation (high λ_t relative to γ) from peaks that require continued external lift.

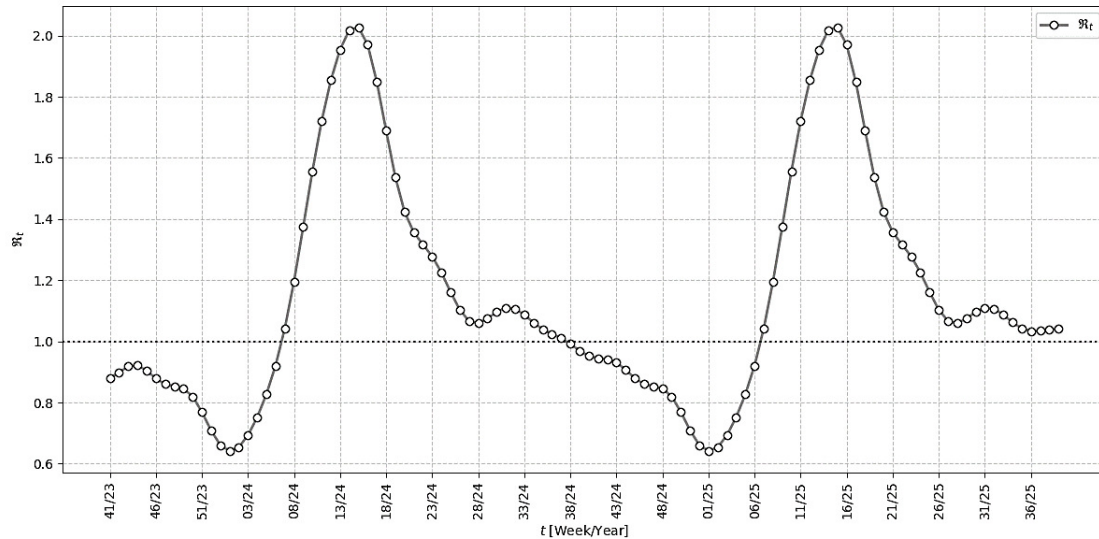


Figure 9. Demand-momentum proxy $\mathfrak{R}_t = \lambda_t/\gamma$ for the SEIRS model; the horizontal line indicates the threshold $\mathfrak{R}_t = 1$.

4.3. Sensitivity and scenario analysis

To assess robustness and planning relevance, we conduct a one-factor-at-a-time (OFAT) sensitivity analysis focused on short-horizon predictive accuracy. Each selected parameter is perturbed over a $\pm 20\%$ grid around its calibrated value while all remaining parameters are held fixed. For each setting, we report in-sample RMSE (RMSE train) and out-of-sample RMSE on the test window (RMSE final). Effect sizes are summarised with a tornado plot (Figure 10), and two scenario sweeps illustrate the qualitative demand implications for the most influential parameters (Figures 11-12).

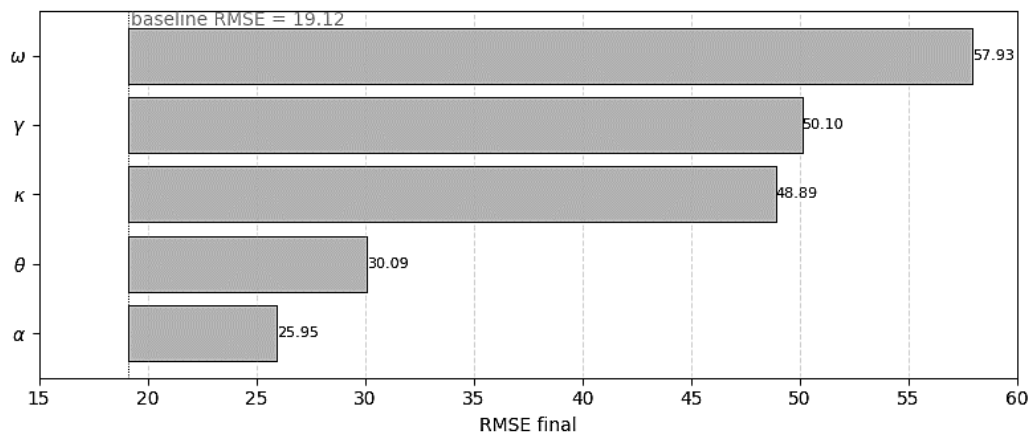


Figure 10. Tornado plot (one-way sensitivity) for RMSE final. Each bar shows the range of RMSE values from Table 3 after changing a single parameter, with the others remaining at their base level. The bars are sorted in descending order by width (the most significant impact at the top). The dashed line indicates the base value of RMSE final.

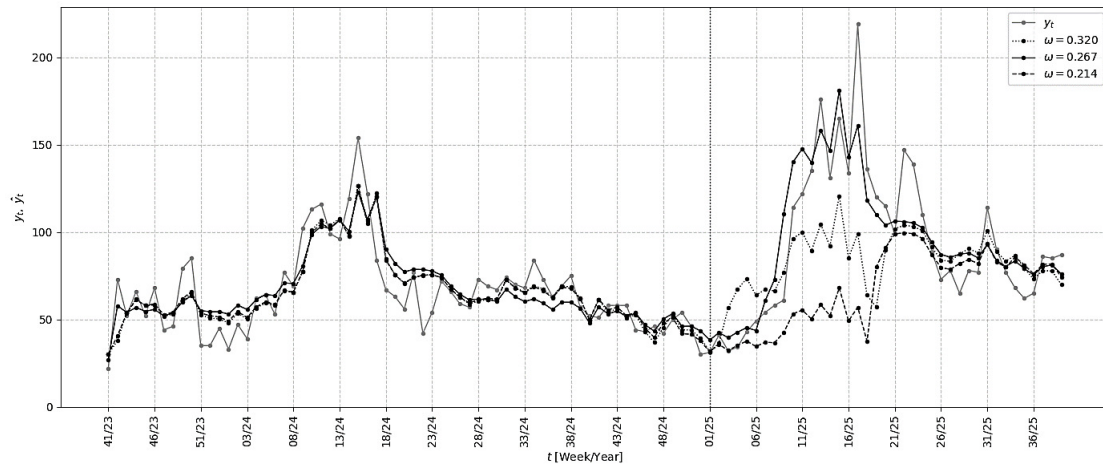


Figure 11. Forecast $\hat{y}_t$ for different values of reactivation factor: $\omega = 0.320, 0.267$ and 0.214 plotted by dotted, solid, and dashed lines, respectively. The observed values of weekly orders y_t is denoted by gray line.

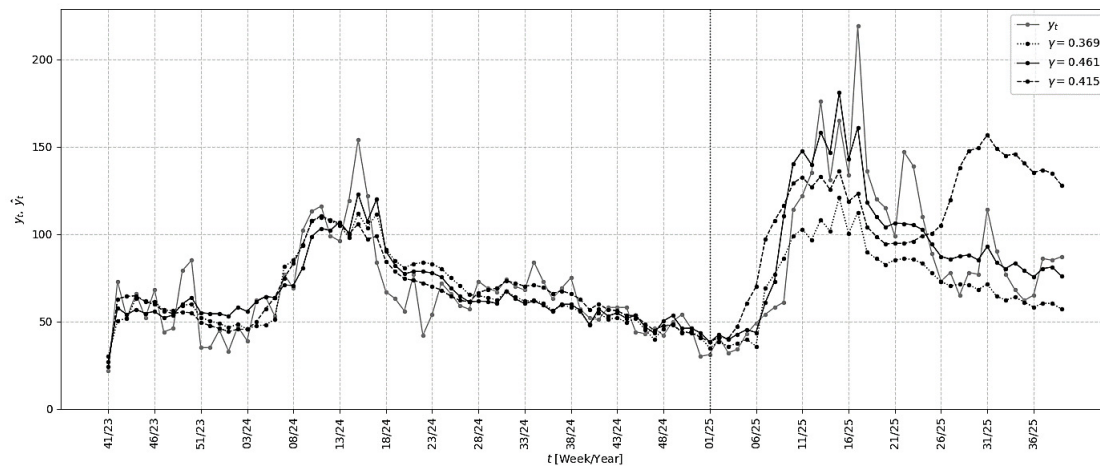


Figure 12. Forecast $\hat{y}_t$ for different values of churn factor: $\gamma = 0.369, 0.461$ and 0.415 plotted by dotted, solid, and dashed lines, respectively. The observed values of weekly orders y_t is denoted by gray line.

Table 3 and Figure 10 show that the test RMSE is most sensitive to the life-cycle transition rates: reactivation ω and churn γ . The scaling parameter κ is the next most influential parameter, reflecting that changes in per-active purchasing intensity translate directly into the observable y_t . More minor but still meaningful effects are associated with θ (seasonal/exogenous driver) and α (nonlinearity of social dependence), which primarily shape peak amplitude and curvature rather than changing the underlying momentum regime. The baseline test-window error is $RMSE_{\text{final}} = 19.1169$ (dashed reference line in Figure 10).

Table 3.

One-factor-at-a-time (OFAT) sensitivity of forecast accuracy. Each parameter is varied by $\pm 20\%$ around its calibrated value (varied values are highlighted in gray) while others are fixed. The table reports train $RMSE_{train}$ and test windows $RMSE_{test}$ (higher values of $RMSE_{test}$ are highlighted in green).

RMSE train	RMSE test	β_0	κ	ω	γ	δ	α	θ
1,519E+01	2,693E+01	-0,817	120	0,267	0,461	0,690	0,960	3,440
1,144E+01	2,505E+01	-0,817	110	0,267	0,461	0,690	0,960	3,440
1,379E+01	1,912E+01	-0,817	100	0,267	0,461	0,690	0,960	3,440
1,263E+01	2,410E+01	-0,817	90	0,267	0,461	0,690	0,960	3,440
1,284E+01	4,889E+01	-0,817	80	0,267	0,461	0,690	0,960	3,440
1,150E+01	5,793E+01	-0,817	100	0,320	0,461	0,690	0,960	3,440
1,258E+01	3,600E+01	-0,817	100	0,293	0,461	0,690	0,960	3,440
1,379E+01	1,912E+01	-0,817	100	0,267	0,461	0,690	0,960	3,440
1,278E+01	3,444E+01	-0,817	100	0,240	0,461	0,690	0,960	3,440
1,278E+01	3,901E+01	-0,817	100	0,214	0,461	0,690	0,960	3,440
1,257E+01	5,010E+01	-0,817	100	0,267	0,553	0,690	0,960	3,440
1,348E+01	4,853E+01	-0,817	100	0,267	0,507	0,690	0,960	3,440
1,379E+01	1,912E+01	-0,817	100	0,267	0,461	0,690	0,960	3,440
1,272E+01	2,529E+01	-0,817	100	0,267	0,415	0,690	0,960	3,440
1,258E+01	3,616E+01	-0,817	100	0,267	0,369	0,690	0,960	3,440
1,328E+01	2,263E+01	-0,817	100	0,267	0,461	0,690	1,150	3,440
1,402E+01	2,068E+01	-0,817	100	0,267	0,461	0,690	1,060	3,440
1,379E+01	1,912E+01	-0,817	100	0,267	0,461	0,690	0,960	3,440
1,331E+01	2,595E+01	-0,817	100	0,267	0,461	0,690	0,860	3,440
1,051E+01	2,565E+01	-0,817	100	0,267	0,461	0,690	0,780	3,440
1,269E+01	3,009E+01	-0,817	100	0,267	0,461	0,690	0,960	4,130
1,267E+01	2,492E+01	-0,817	100	0,267	0,461	0,690	0,960	3,780
1,379E+01	1,912E+01	-0,817	100	0,267	0,461	0,690	0,960	3,440
1,274E+01	2,287E+01	-0,817	100	0,267	0,461	0,690	0,960	3,100
1,274E+01	2,462E+01	-0,817	100	0,267	0,461	0,690	0,960	2,750

Figures 11 and 12 translate these relationships into demand (conversion) time history. Increasing reactivation ω accelerates replacement of the susceptible individuals pool ($R \rightarrow S$), leading to faster customer recoveries and higher predicted orders during volatile periods, whereas lower ω delays recovery and reduces demand rebuild. Varying churn γ primarily controls the persistence of activity: higher γ shortens active spells, truncates peaks, and produces faster post-peak decay; lower γ prolongs activity and raises plateau levels through stronger carry-over across weeks. Together, the OFAT ranking and scenario indicate that churn and win-back dynamics are first-order levers for both forecast performance and the qualitative shape of cycles, while θ and α mainly re-scale predictable seasonal amplitude and responsiveness to the active share.

5. Discussion, managerial implications, and conclusions

This case study shows that a state-space SEIRS e-commerce customer life-cycle model improves short-horizon demand forecasts and provides interpretable diagnostics for marketing- and seasonality-driven demand. In particular, the model outperforms a SARIMA benchmark and yields residuals with weaker serial dependence, suggesting that part of the temporal structure is captured via latent exposure–activation mechanisms rather than absorbed by autoregressive extrapolation. This result is consistent with the broader marketing diffusion tradition that emphasises structured mechanisms behind observed adoption or demand dynamics (Bass, 1969; Peres, Muller, Mahajan, 2010), and with evidence that epidemic-style thinking can be informative for diffusion processes under social influence (Fibich, 2016; McAdams, Song, 2025; Woo, Chen, 2016). In this regard, the empirical findings support **H1**.

The proposed latent states also support a behavioural interpretation of demand cycles that goes beyond purely statistical seasonality. Increases in the time-varying transmission intensity λ_t tend to precede increases in the active state I_t , consistent with a lead-lag mechanism: marketing pressure and seasonality first shift the exposed group and then translate into purchases through conversion. Similar lead-lag logic underpins surveillance-oriented state-space approaches in epidemiology, where latent intensities are tracked to anticipate subsequent changes in observed incidence (Papageorgiou, Tsaklidis, 2023; Prashad, 2025). The proxy of the demand growth rate (momentum) $\mathfrak{R}_t = \lambda_t/\gamma$ provides a compact diagnostic of whether exposure inflows are sufficient to offset churn weekly; sustained periods above (below) 1 correspond to expansive (recessive) configurations in terms of order numbers. This mirrors the role of the epidemic reproduction number as a regime indicator in epidemiology and its real-time estimation practice (Kermack, McKendrick, 1927; Nash, Nouvellet, Cori, 2022), thereby supporting **H2** and **H4** in the e-commerce management context.

Sensitivity analyses further clarify which mechanisms dominate in short-term matching and managerial leverage. Forecast error in the test window is most sensitive to life-cycle changes related to customer churn γ and reactivation ω , indicating that retaining and regaining customers determines the pace of recovery after peaks and slowdowns, while other parameters primarily reshape predictable seasonal amplitude and responsiveness to conversion. This complements applied churn research, where predictive pipelines are often framed around identifying customers at risk of leaving (Dias, Antonio, 2025), and aligns with recent emphasis on explainability when churn-related outputs are used for intervention timing and decision support (Kimitei et al., 2025). Unlike churn treated as a standalone classifier, the SEIRS formulation integrates customer loss and reactivation directly into the demand system, consistent with the hypothesis that these mechanisms influence demand trajectories, supporting **H3**.

This case study shows that a state-space SEIRS e-commerce customer life-cycle model improves short-horizon demand forecasts and provides interpretable diagnostics for marketing- and seasonality-driven e-commerce demand. Empirically, the forecast outperforms a SARIMA benchmark and leaves residuals with weaker serial dependence, consistent with capturing exposure–activation dynamics rather than extrapolating past levels.

6. Conclusions

The proposed state-space SEIRS e-commerce framework is a marketing analysis tool that combines weekly orders with an e-commerce customer life-cycle model. It segments customers by life-cycle stage, improving trend prediction and strategic planning for customer retention.

Two implications are beneficial. In marketing campaign management, stabilizing the number of orders is mainly a retention and reactivation task: lowering churn (γ) lengthens active spells and slows post-peak orders number decay, while higher reactivation (ω) speeds recovery by replenishing the susceptible pool. Paid media works best when λ_t and $\mathfrak{R}_t$ increase, higher spend is more likely to be amplified, whereas when $\mathfrak{R}_t < 1$, short external impulses may be necessary to restore dynamics.

Operationally, a compact dashboard can track time-varying transmission intensity λ_t as an early-warning signal, the value of the demand-momentum proxy $\mathfrak{R}_t$ (relative to 1), and churn/reactivation (γ, ω). Short-term forecasts and residual checks should appear alongside to signal emerging deviations from expected values and guide paid media spending. In the weekly planning–execution–review cycle, λ_t and R_t set the pace, while γ and ω set retention and recovery priorities, creating a shared view of demand shifts. Following the distinction between real-time monitoring and predictive analytics in organisational operations (Wolniak, 2023), the proposed indicators can be positioned as a compact monitoring layer that complements forecasting.

This study has several limitations. It relies on weekly aggregates from a single retailer and uses a limited representation of marketing exposure and other exogenous drivers. The model also assumes a homogeneous population and captures channel effects in reduced form, which limits campaign-level causal inference. Future research will validate the approach on additional cases (other retailers and product categories) to assess external validity and boundary conditions. Further extensions include richer driver constructions (e.g., adstock/carry-over, multi-channel structure, moving-holiday effects) and probabilistic uncertainty reporting for latent states and indicators.

Declarations

Funding: This research received no external funding.

Data availability: The dataset is proprietary retailer data and cannot be publicly shared. Aggregated series or derived indicators may be provided upon reasonable request. Conflict of interest: The authors declare no conflict of interest.

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SUSTAINABILITY TRADE-OFFS UNDER ECONOMIC GROWTH IN THE LOGISTICS SECTOR: EVIDENCE FROM SELECTED CEECS

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Purpose: This paper examines the relationship between economic growth and the sustainability of the logistics sector in selected Central and Eastern European countries. It investigates whether this relationship is non-linear, varies across countries, and depends on inflationary and labour-market conditions.

Design/methodology/approach: Using annual panel data for 2008-2024 from Eurostat Structural Business Statistics for Poland, Czechia, Slovakia, Hungary, and Romania. The study is based on a composite sustainability index covering economic, social, and environmental dimensions. The fixed model includes a quadratic form of GDP, interactions between countries and GDP, and interactions between GDP, HICP and unemployment. The robust standard errors method is used.

Findings: GDP is positively associated with logistics-sector sustainability, while the trade balance is negatively related. The GDP-sustainability link is non-linear, with diminishing marginal effects. The strength of the relationship varies across countries, with the most significant impact in Slovakia. No systematic moderating role of inflation or unemployment is found.

Research limitations/implications: The analysis is based on aggregated sector-level indicators and a composite index; therefore, firm-level mechanisms cannot be inferred from these data. Future research might incorporate micro-level data, institutional drivers, and dynamic modelling.

Practical implications: Sustainable policies in the logistics sector should not necessarily be supported by growth factors and should include specific support for low-emission technologies, which may vary from country to industry.

Social implications: The results indicate that economic growth alone is not a guarantee of development that is both socially and environmentally balanced, thus supporting the need to enforce measures to boost green investments and labour standards to enhance environmental quality and labour stability, respectively.

Originality/value: The paper offers sector-level evidence on growth-sustainability trade-offs in CEEC logistics using a composite sustainability index, with tests for non-linearity and cross-country heterogeneity, in a single fixed-effects approach.

Keywords: sustainable development; logistics sector; economic growth.

Category of the paper: Research paper.

1. Introduction

One of the main challenges for the logistics sector in Eastern European countries is achieving the Sustainable Development Goals (Fikus, Liszka, 2024). EU legal solutions and increasing competitiveness and social awareness require companies to reduce greenhouse gas emissions, generate profits, and meet social expectations (Mariani et al., 2022; Kwilinski et al., 2023; Govindan, 2025). Furthermore, the sector must operate under changing macroeconomic and geopolitical conditions, the development of automation and new technologies, and fluctuating energy prices (Barbieri, Capoani, 2025; Semrau, 2025).

In this study, the logistics sector is understood in line with the European Union's statistical classification of economic activities (NACE Rev.2, Section H), which covers transportation and storage services, including land, water and air transport, warehousing, and supporting activities for transportation. This definition ensures conceptual consistency and comparability across the analysed countries.

Logistics is essential for economic growth, job creation, and the support of other industries (Khan et al., 2022; Krykavskyy et al., 2023; Bartosiewicz et al., 2025). On the other hand, its development causes damage to the natural environment, mainly due to the sector's high emission intensity (Li et al., 2025). This raises the question of whether economic growth promotes sustainable logistics development or whether it entails heterogeneous effects and potential sustainability trade-offs.

Previous studies show that economic growth has a significant impact on logistics sustainability (Comporek et al., 2022; Misztal, 2022; Barut et al., 2023). Moreover, the effects of the trade, inflation, and the labour market in the logistics sector also play a role (Ozcelebi et al., 2021; Chrysanthopoulou et al., 2025). However, the results of these studies are not conclusive. Several studies suggest that economic growth is associated with greater implementation of SDG goals (Bartosiewicz et al., 2025; Gniadkowska-Szymańska et al., 2025). Some researchers present different opinions. McNeil and Barnes (2025) and Güler et al. (2025) note that pressures to increase production, consumption, and competitiveness can lead to greater negative environmental impacts. Sectors highly dependent on energy prices, transportation costs, and developments in other sectors are particularly vulnerable. The logistics sector remains underexplored in the academic literature in Central and Eastern European countries.

Furthermore, there is a lack of analyses that simultaneously consider the variation in outcomes across countries and their stability under changing macroeconomic conditions. The study contributes to the literature by providing a sector-specific panel analysis of sustainability trade-offs under economic growth in Central and Eastern Europe. The analyses take into account significant differences between countries and macroeconomic conditions.

This paper empirically analyses the relationship between economic growth and sustainable development in the logistics sector across selected Central and Eastern European countries. In particular, an analysis gives a new perspective and empirical evidence on sector-level sustainability trade-offs under economic growth. The study extends previous research, which mainly focused on simultaneously addressing non-linear effects, cross-country heterogeneity, and the conditional role of macroeconomic factors within a unified panel framework.

The study focuses on Poland, the Czechia, Slovakia, Hungary, and Romania. These countries have a common experience of systemic transformation and integration with the European Union. Moreover, they differ in logistics sector development and economic growth. These conditions enable the analysis of cross-country heterogeneity within a relatively similar institutional framework.

The study period, from 2008 to 2024, was characterised by disturbances such as the economic crisis, the COVID-19 pandemic, and the Ukraine War.

The study is based on Eurostat Structural Business Statistics and employs panel regression models with country- and year-fixed effects. This approach ensures control for unobserved heterogeneity and common time shocks. Interaction terms are then introduced to assess cross-country differences and the conditional nature of the estimated effects.

The paper is structured as follows: introduction, theoretical background, methodology, research results, discussion, and conclusions.

2. Theoretical background

2.1. Economic growth and sustainable development in the logistics sector

Economic growth leads to higher demand for transportation, warehousing, and distribution services (Andreoli et al., 2010; Comporek et al., 2022; da Silva et al., 2023; Bartosiewicz et al., 2025). Due to the increased demand for logistics services, the sector's financial results are improving and contributing to a greater share in GDP growth (Mahmood et al., 2025).

However, the impact of economic growth on the sustainable development of the logistics sector is not straightforward to interpret. GDP growth favours investments and the implementation of eco-innovations, which can generate additional profits and reduce the environmental footprint (Demirel et al., 2025; Ogbuabor et al., 2026). On the other hand, increasing the scale of logistics activity is associated with greater transport congestion, greater energy intensity, greenhouse gas emissions, and rising cost pressures (Tundys, Wiśniewski, 2026).

It is essential to note that the impact of macroeconomic conditions on the sustainable development of the logistics sector varies across time horizons (Gniadkowska-Szymańska et al., 2025; Baydar, Mete, 2026). If economies of scale result from pollution havens, environmental damage may increase in the short term (Bagchi, Sahu, 2025). In the long run, technological and organisational effects may improve the sector's environmental and economic performance (Guo et al., 2025). The direction of these processes is determined by the level of economic development, the sector's structure, and legal regulations. The impact of economic growth on the logistics sector can be understood through its effects on scale, structure, and technology (Delfin-Ortega, 2025; Yunxia, Yuqing, 2025). These mechanisms determine the nature of tensions between the Sustainable Development Goals.

From a broader theoretical perspective, the growth–sustainability nexus can be framed within the Environmental Kuznets Curve (EKC). In early stages of development, economic expansion increases environmental pressure, whereas at higher income levels structural change and technological progress may mitigate it. In the logistics sector, this implies a potentially non-linear relationship, with diminishing marginal sustainability effects as economies develop.

In this study, sustainable development of the logistics sector is understood as development in three dimensions: economic, environmental, and social (Khan et al., 2025; Kholaif, Tang, 2025). This approach assumes the need to combine logistics profitability with reducing negative environmental impacts and supporting the labour market (Comporek et al, 2022; Boşcoianu et al., 2025). This understanding of sustainable development implies the possibility of trade-offs between individual goals (Fertő, Harangozó, 2025; Holden et al., 2025), justifying the need for an empirical analysis of the relationship between economic growth and logistics sector development.

2.2. Sustainability Trade-offs in the Logistics Sector

In this study, a sustainability trade-off refers to tensions in which higher economic activity supports sustainability outcomes. However, the marginal gains weaken as the scale of activity increases, and may coincide with adverse effects on external balance indicators. As a result, trade-offs are analysed using the non-linear effects of GDP and the sign of the trade balance coefficient in the fixed-effects mode. In this interpretation, the trade balance is treated as a proxy for scale-related pressures associated with cross-border freight intensity, rather than a direct measure of sustainability.

Sustainable development of the logistics sector entails trade-offs among economic, environmental, and social objectives (Misztal, 2022; Vimal et al., 2025). The logistics firm would need to guarantee quality and on-time delivery while remaining profitable. With that happening, achieving environmental and/or social objectives can effectively threaten economic objectives (Murawski, 2025; Barbieri, Capoani, 2025).

Sustainability trade-offs in logistics primarily concern investment decisions (Akbar et al., 2025; Hoang et al., 2025). Implementing capital-intensive environmental projects is difficult, primarily due to rising prices (Sharma et al., 2025). In the social dimension, higher economic returns do not automatically improve working conditions (Gilardi, Lazazzara, 2025).

The scope and intensity of trade-offs depend on macroeconomic conditions and the level of sectoral development (Gniadkowska-Szymańska et al., 2025; Bartosiewicz et al., 2025b). In some cases, tensions between sustainability objectives can be mitigated. In others, conflicts persist between the pillars of sustainable development (Kareem et al., 2025). Therefore, identifying trade-offs requires empirical analysis that accounts for cross-country differences and temporal changes.

In this study, trade-offs are analysed at the logistics sector level. Empirically, these trade-offs are examined by combining sustainability index results with estimated effects on the trade balance, reflecting scale-related pressures associated with growth.

3. Research objectives, hypothesis, and research questions

Previous studies present that the relationship between economic growth and the sustainable development of the logistics sector may vary across economies (Comporek et al., 2022; Semrau, 2025). Economic growth can support investments, but it may also intensify sustainability trade-offs related to the scale of logistics activity (Vimal et al., 2025). The literature emphasises the importance of country-specific characteristics and selected macroeconomic conditions in shaping these relationships (Krykavskyy et al., 2023; Bartosiewicz, 2025).

The research goal is to examine the relationship between economic growth and SD in selected CEECs. The analysis focuses on identifying the direction and strength of this relationship, as well as its heterogeneity across countries.

Based on these considerations, the following central research hypothesis (H) is formulated: "Economic growth is associated with changes in the level of sustainability of the logistics sector, while the magnitude of this relationship differs across countries".

To address the primary hypothesis, the study is guided by the following research questions:

- Is economic growth associated with changes in the level of sustainability of the logistics sector?
- Does the strength of this relationship differ across the analysed Central and Eastern European countries?
- Do selected macroeconomic conditions, in particular inflation and labour market conditions, influence the relationship between economic growth and sustainability in the logistics sector?

These research objectives, hypotheses, and questions provide the basis for selecting the data and the empirical strategy applied in the subsequent sections of the paper.

4. Data and methodology

4.1. Data and Variables

The empirical analysis utilises annual panel data from 2008 to 2024 for Poland, the Czechia, Slovakia, Hungary, and Romania. All analytical indicators come from Eurostat's Structural Business Statistics. It ensures cross-country comparability and consistency over time.

The dependent variable is a composite indicator for the sustainable development of the logistics sector. The indicator considers three aspects of sustainability: economic, environmental, and social. The indicator is developed using sector-specific indicators.

Economic growth is the primary explanatory variable, which is measured by GDP. To control for the macroeconomic approach used in sustainability research and for sector performance, a series of macroeconomic control variables is considered. These include the trade balance deficit or surplus, HICP and the unemployment rate.

Selected variables are expressed in logarithmic form to reduce scale effects and facilitate interpretation of the estimated coefficients.

4.2. Construction of the Sustainability Index

The sustainability of the logistics sector is measured by a composite index which integrates economic, social, and environmental aspects. Let denote the country's sustainability index (SD_{it}) in the year. The index is calculated as the arithmetic mean of normalised analytical indicators according to the following expression:

$$SD_{it} = \frac{1}{K} \sum_{j=1}^K \left[\delta_j \cdot \frac{x_{ijt}}{\max_i(x_{ijt})} + (1 - \delta_j) \cdot \frac{\min_i(x_{ijt})}{x_{ijt}} \right] \quad (1)$$

where:

x_{ijt} represents the value of analytical indicator j for country i in year t ,

K is the total number of indicators included in the index,

$\delta_j \in \{0,1\}$ is a binary parameter identifying the direction of the indicator. For stimulants ($\delta_j = 1$), higher values indicate better sustainability performance, while for destimulants ($\delta_j = 0$), lower values correspond to more favourable outcomes. The minimum and maximum values are determined across countries for each year to ensure cross-country comparability.

The set of analytical indicators mirrors the multifaceted nature of sustainability in the logistics field. The economic dimension of sustainability measures the size, productivity, profit, and investment of the logistics companies. The social dimension of sustainability reflects the labour market, wages, labour force productivity, and labour-related cost structures. The environmental dimension of sustainability measures indicators relates to the pressure logistics exerts on the environment; the lower the pressure, the more sustainable the practice of logistics.

All indicators are given equal weight in the aggregation process, ensuring transparency and avoiding subjective assumptions about their relative importance. The index is sector-specific and serves to compare the level of logistics sustainability over time and across countries.

The index captures relative sustainability performance across countries and over time and is intended for comparative rather than absolute evaluation.

4.3. Empirical Strategy

The analysis is based on the panel data models that allow for controlling unobserved heterogeneity across countries and common time effects. All specifications are estimated using fixed effects for countries and years.

The baseline specification examines the average relationship between economic growth and the sustainability of the logistics sector across the analysed countries. The model is specified as follows:

$$SD_{it} = \alpha + \beta_1 \ln(GDP_{it}) + \beta_2 TB_{it} + \beta_3 \ln(W_{it}) + \beta_4 U_{it} + \beta_5 HICP_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

where:

SD_{it} denotes the sustainability index of the logistics sector in country i and year t ,

$\ln(GDP_{it})$ represents economic growth,

TB_{it} is the trade balance,

$\ln(W_{it})$ denotes wages,

U_{it} is the unemployment rate,

$HICP_{it}$ captures inflation. Country fixed effects μ_i control for time-invariant country-specific characteristics, while year fixed effects λ_t capture common shocks.

To examine potential non-linearities and diminishing returns in the relationship between economic growth and sustainability, an extended specification that includes a quadratic term for economic growth is estimated. It allows for identifying potential sustainability trade-offs associated with the scale effect of economic activity.

$$SD_{it} = \alpha + \beta_1 \ln(GDP_{it}) + \beta_2 (\ln(GDP_{it}))^2 + X'_{it} \delta + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

A positive value of β_1 combined with a negative value of β_2 would indicate diminishing marginal effects of economic growth on sustainability, consistent with the existence of sustainability trade-offs.

To examine whether the effect of economic growth differs across countries, interaction terms between economic growth and country-specific dummy variables are introduced. Poland serves as the reference country. The model is specified as:

$$SD_{it} = \alpha + \beta_1 \ln(GDP_{it}) + \sum_{c \neq PL} \gamma_c [\ln(GDP_{it}) \times D_{ic}] + X'_{it} \delta + \mu_i + \lambda_t + \varepsilon_{it} \quad (4)$$

where:

D_{ic} is a dummy variable equal to one for country c and zero otherwise,

X_{it} is the vector of control variables included in the baseline model. The implied country-specific effect of economic growth is obtained as the sum of the baseline coefficient and the corresponding interaction term.

To assess whether macroeconomic conditions modify the relationship between economic growth and sustainability, interaction terms between economic growth and selected macroeconomic variables are included. The conditional specification is given by:

$$SD_{it} = \alpha + \beta_1 \ln(GDP_{it}) + \beta_2 Z_{it} + \beta_3 [\ln(GDP_{it}) \times Z_{it}] + X'_{it} \delta + \mu_i + \lambda_t + \varepsilon_{it} \quad (5)$$

where Z_{it} represents either inflation (HICP) or the unemployment rate (U).

All of these estimations are run using fixed-effect estimators with robust standard errors to correct for heteroscedasticity. As robustness tests, different standard error estimators, such as country-clustered and Driscoll & Kraay standard errors, are employed to ensure that the baseline findings remain consistent.

Note that, because the cross-sectional dimension of the panel is relatively small (five countries), the empirical approach emphasises fixed-effects models over dynamic panel models. The goal of the empirical work is to uncover structural and cross-sectional heterogeneities in the relationship between growth and sustainability, rather than dynamic patterns of adjustment.

4.4. Potential endogeneity and identification considerations

A primary methodological concern in exploring the growth-sustainability link is endogeneity, driven by the spectre of reverse causality and omitted variables correlated with economic growth and sectoral sustainability. To empirically address such problems, the methodological design assumes country- and year-fixed effects to control for omitted-variable bias in testing cross-sectional fixed effects alongside standard shocks. Furthermore, it controls for relevant macroeconomic aggregates such as trade balance, inflation, unemployment rates, and wages. It is important to note that the results are interpretive and conditional. Nevertheless, it is vital to note that the sample is small ($N = 5$), for which dynamic group mediation or the instrumental variable technique would not be statistically justified.

In this case, the methodological approach is premised on the use of fixed effects and robustness tests with clustered robust standard errors, as well as Driscoll-Kraay standard errors.

5. Research results

Table 1 presents both descriptive statistics and long-term trends of the Sustainable Development Index in the analysed countries. The results indicate considerable cross-country differences in the levels and variability of SD, along with heterogeneous growth paths over time. In particular, countries with lower initial SD levels often exhibit stronger upward trends, which motivates further panel analysis of the role of economic growth and macroeconomic conditions.

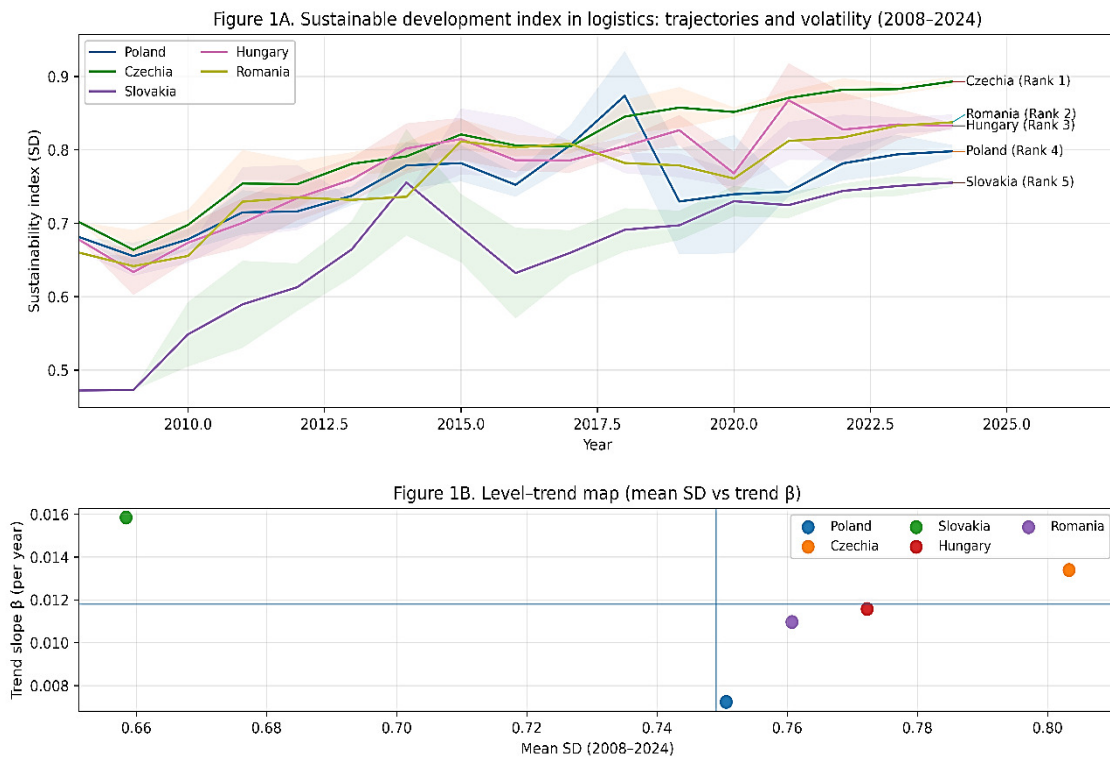
Table 1.

Descriptive statistics and trends in sustainable development (SD) in selected Central and Eastern European countries

Country	Mean SD	Std. dev.	Min	Max	Trend (β)	t-stat	R ²	Obs.
Czechia	0.803	0.070	0.664	0.893	0.0134	13.87	0.928	17
Hungary	0.772	0.067	0.633	0.868	0.0116	6.98	0.764	17
Poland	0.751	0.055	0.655	0.874	0.0072	3.50	0.449	17
Romania	0.761	0.063	0.641	0.837	0.0110	7.32	0.781	17
Slovakia	0.658	0.092	0.472	0.756	0.0158	6.69	0.749	17

Source: Eurostat (SBS, sbs_sc_oww).

Figure 1 above shows the SD index for the period ranging from 2008 to 2024. From the trends across all countries, it is evident that SD is rising, though it experiences fluctuations. Czechia experiences a steadily rising trend, while Poland and Hungary record fluctuations. Romania shows a less steeply rising trend, while Slovakia shows the most significant improvements over time despite recording the lowest starting point.



Source: Eurostat Structural Business Statistics (sbs_sc_oww); authors' calculations.

Figure 1. Evolution of the sustainable development index in the logistics sector (2008–2024).

Source: Eurostat (SBS, sbs_sc_oww).

Table 2 presents the results of the fixed-effects regression on the SD index. The estimated model exhibits strong explanatory power ($R^2 = 0.925$) and a statistically significant F-statistic. Economic growth, as measured by $\ln(\text{GDP})$, is positively and statistically significantly associated with sustainable development, whereas the trade balance is negatively and significantly associated with the sustainability index. The inclusion of country and year fixed effects confirms that the estimated relationships are identified after controlling for unobserved country-specific characteristics and common time effects.

Table 2.

Baseline fixed-effects regression results for sustainable development (SD)

Panel A. Coefficient estimates			
Variable	Coefficient	Robust SE	z-stat
$\ln(\text{GDP})$	0.118	0.041	2.88
Trade balance	−0.000002	0.0000004	−4.48
$\ln(\text{Wages})$	−0.080	0.074	−1.09
Unemployment	0.008	0.007	1.16
HICP	−0.003	0.003	−1.12
Panel B. Model diagnostics and specification tests			
Country fixed effects/ Year fixed effects	Yes	F-statistic (model)	53.01
Observations	85	Prob > F	0.000
Number of countries	5	Durbin–Watson statistic	1.51
Within R^2	0.925		

Source: Eurostat (SBS, sbs_sc_oww).

Including a quadratic term for economic growth reveals a statistically significant non-linear relationship between GDP and the sustainable development of the logistics sector (Table 3). While the linear GDP term is positive and significant, the negative and significant squared term indicates diminishing marginal effects of economic growth on sustainability. This suggests that economic growth supports sustainability improvements, although its marginal contribution weakens at higher levels of GDP.

Table 3.

Non-linear effects of economic growth on sustainable development (FE)

Panel A. Coefficient estimates			
Variable	Coefficient	Robust SE	z-stat
ln(GDP)	1.465	0.654	2.24
(ln(GDP)) ²	-0.058	0.023	-2.56
Trade balance	-0.000001	0.0000004	-2.41
ln(Wages)	-0.076	0.071	-1.07
Unemployment	0.009	0.007	1.29
HICP	-0.003	0.003	-1.01
Panel B. Model diagnostics			
Country/ year fixed effects:	YES	Prob	> F: 0.000
Observations	85	Within R ²	0.931
Number of countries	5	Durbin–Watson statistic	1.54
F-statistic (model): 49.87			

Source: Eurostat (SBS, sbs_sc_oww).

Table 4 presents cross-country heterogeneity. The fixed-effects interaction model, with Poland as the reference country, shows that the impact of economic growth differs across countries, with the effect significantly stronger in Slovakia. At the same time, differences in Czechia, Hungary, and Romania are not statistically significant. Panel B shows that the implied effects of economic growth on sustainable development are positive across all countries, but statistically significant only for Slovakia. Panel C confirms good model fit and joint statistical significance.

Table 4.

Country-specific effects of economic growth on sustainable development (SD)

Panel A. Coefficients (differences in GDP effect vs Poland)			
Variable	Coefficient	Robust SE	z-stat
ln(GDP) [Poland baseline]	0.134	0.174	0.769
ln(GDP)×Czechia (diff vs PL)	0.051	0.065	0.783
ln(GDP)×Hungary (diff vs PL)	0.050	0.074	0.678
ln(GDP)×Romania (diff vs PL)	-0.054	0.081	-0.658
ln(GDP)×Slovakia (diff vs PL)	0.238	0.076	3.135
Trade balance	-0.000	0.000	-1.282
ln(Wages)	-0.072	0.110	-0.654
Unemployment	0.016	0.007	2.294
HICP	-0.005	0.003	-1.760

Cont. table 4.

Panel B. Implied GDP effect in each country (β_{total})			
Country	Implied GDP effect (β)	Robust SE	z-stat
Poland	0.134	0.174	0.769
Czechia	0.185	0.163	1.134
Hungary	0.184	0.160	1.149
Romania	0.080	0.176	0.455
Slovakia	0.372	0.184	2.019
Panel C. Model diagnostics			
Country FE/ Year FE	Yes	Adj. R ²	0.918
Number of countries	5	F-statistic (joint significance)	91.242
Observations	85	Prob > F	0.000
R ²	0.946	Durbin–Watson statistic	1.823

Source: Eurostat (SBS, sbs_sc_ovw).

Figure 2 shows substantial cross-country heterogeneity in the GDP–SD relationship, with Slovakia exhibiting a significantly more potent effect than the other analysed countries.

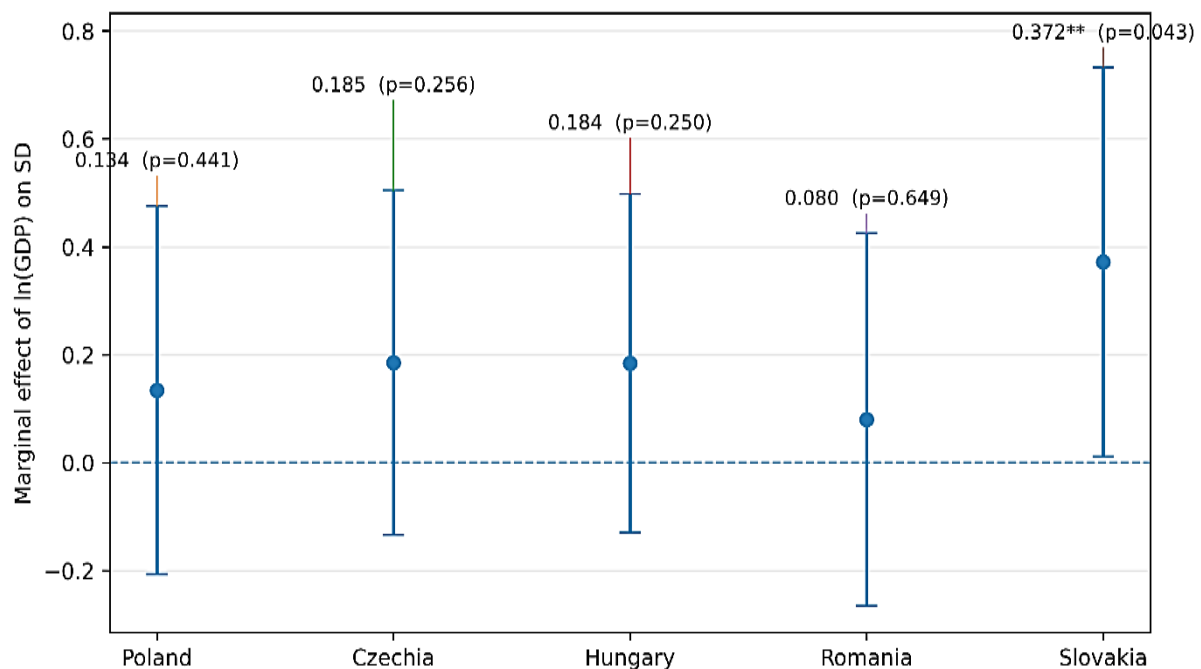


Figure 2. Country-specific marginal effects of economic growth on SD

Source: Eurostat (SBS, sbs_sc_ovw).

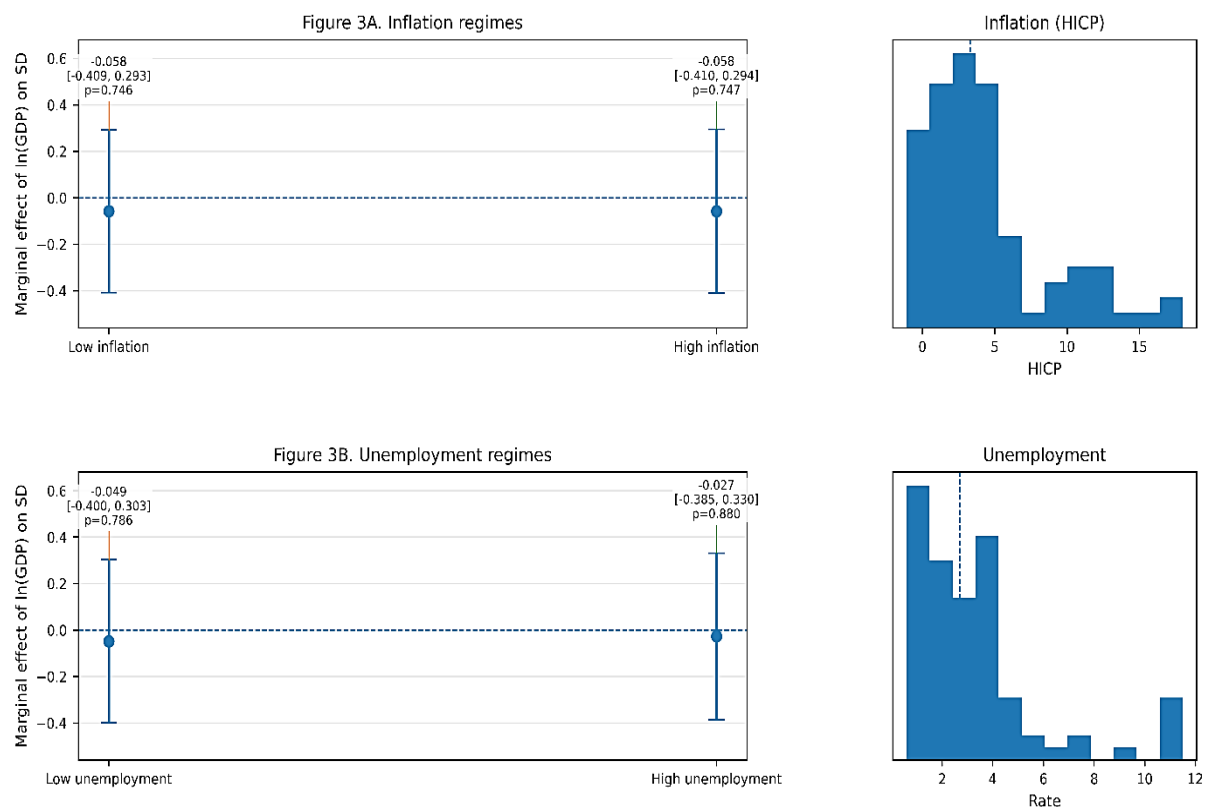
Table 5 assesses whether the impact of economic growth on the sustainable development of the logistics sector is conditional on inflation and labour-market conditions. The fixed-effects interaction model shows that neither inflation nor unemployment significantly modifies the growth–sustainability relationship, while the trade balance remains negatively and statistically significant. Model diagnostics indicate a good overall fit and confirm that the estimated coefficients reflect average effects across the analysed countries.

Table 5.*Economic growth–sustainability trade-offs under inflationary and labour-market pressures*

Panel A. Coefficient estimates			
Variable	Coefficient	Robust SE	z-stat
ln(GDP)	−0.058	0.179	−0.33
HICP	0.000	0.021	0.02
ln(GDP) × HICP	−0.000	0.002	−0.16
Unemployment	−0.056	0.073	−0.77
ln(GDP) × Unemployment	0.006	0.007	0.88
Trade balance	−0.000001	0.000001	−2.28
ln(Wages)	−0.110	0.075	−1.47
Panel B. Model specification and diagnostics			
Country/ Year fixed effects	Yes	F-statistic (joint significance)	52.68
Number of countries	5	Prob > F	0.000
Observations	85	Durbin–Watson statistic	1.52
Within R ²	0.926		

Source: Eurostat (SBS, sbs_sc_ovw).

Figure 3 shows that the marginal effect of economic growth on sustainable development is not statistically significant across inflation and unemployment regimes, indicating no systematic macroeconomic trade-offs.

**Figure 3.** Effect of economic growth on SD under inflation and unemployment regimes.

Source: Eurostat (SBS, sbs_sc_ovw).

Overall, the results indicate a positive relationship between economic growth and the sustainable development of the logistics sector, with substantial cross-country heterogeneity and no evidence of systematic macroeconomic trade-offs.

5. Discussion

Previous research on the relationship between economic growth and sustainable development in the logistics sector has yielded mixed conclusions (Comporek et al., 2022; Misztal, 2022). Some researchers suggest that economic growth has a positive impact on the economic, social and environmental pillars of the logistics sector (Bartosiewicz et al., 2025; Gniadkowska-Szymańska et al., 2025). Others underline that logistics development can hurt the natural environment (Li et al., 2025; Barut et al., 2023). The obtained results are consistent with this research trend, confirming that this relationship is not uniform and depends on national conditions and the specific research methodology employed (Misztal, 2022).

The research results confirm a substantial relationship between economic growth and the sustainable development of the logistics sector (Comporek et al., 2022). The answer to the first research question is therefore affirmative. Economic growth promotes improved sustainable development. This result suggests that as economic activity increases, so do the opportunities for companies to invest in the social and environmental spheres (Demirel et al., 2025; Guo et al., 2025). The non-linear pattern observed in the results suggests diminishing marginal sustainability gains from economic growth in the logistics sector. This pattern is consistent with the Environmental Kuznets Curve: early growth increases environmental pressure through scale effects, while at higher income levels structural and technological improvements mitigate it. The diminishing marginal effect in logistics reflects the shift from expansion-driven growth to efficiency and low-emission adjustments.

At the same time, the results indicate significant variation in the strength of this relationship between the analysed countries (Bartosiewicz et al., 2025). Therefore, the answer to the second research question is affirmative, although the strength of the effect differs considerably across countries. The strongest and statistically significant effect of economic growth was observed in Slovakia. In the remaining countries, this relationship was weaker or statistically ambiguous. This means that economic growth does not translate equally into sustainable development of the logistics sector in all economies (Krykavskyy et al., 2023). Structural factors play a key role, including the level of infrastructure development, the structure and level of development and innovation within the sector, and the general business environment (da Silva et al., 2023; Mahmood et al., 2025).

The conditional analysis did not confirm that inflation and unemployment significantly moderate the impact of economic growth on the sustainable development of the logistics sector. Therefore, the third research question was not empirically supported. This result suggests that short-term macroeconomic fluctuations have a limited impact on this relationship (Ozcelebi et al., 2021; Chrysanthopoulou et al., 2025). However, long-term processes in which the effects of investment are visible are significant (Gniadkowska-Szymańska et al., 2025).

The negative impact of the the trade balance on the sustainability of the logistics sector remains a significant element of the discussion (Barut et al., 2023). This may indicate that the increased intensity of freight flows is associated with additional environmental costs (Li et al., 2025). This result confirms the existence of real trade-offs between increased logistics activity and sustainable development goals (Fertő, Harangozó, 2025; Vimal et al., 2025).

The results confirm a relationship between economic growth and the sustainable development of the logistics sector, with cross-country differences in the magnitude of this relationship. No evidence is found for conditional effects related to inflation or labour-market conditions (Comporek et al., 2022; Bartosiewicz et al., 2025).

The study has certain limitations. The analysis is based on aggregated sector-level data. This approach limits the ability to identify the mechanisms operating within enterprises. Also, the method used to calculate the synthetic indicator may influence the resulting estimation models (Holden et al., 2025). The analysis is limited to selected Central and Eastern European countries, which constrains the generalisability of the results.

The study's results suggest several important practical implications. First, supporting the sustainable development of the logistics sector should not be based solely on stimulating economic growth. It is essential to implement appropriate legal regulations to support business processes in the sector (Murawski, 2025). Implementing facilitation measures and creating financial mechanisms to support logistics SD should be key here (Kholaf, Tang, 2025). Public policy at both national and EU levels should prioritise support for low-emission and energy-efficient technologies in the logistics sector (Barbieri, Capoani, 2025; Tundys, Wiśniewski, 2026).

Future research may extend the current study by adding microeconomic evidence, using dynamic and non-linear modelling approaches, and even extending to broader geographic and institutional contexts (Akbar et al., 2025; Bagchi, Sahu, 2025; Krykavskyy et al., 2023).

6. Conclusions

This paper examines the connection between economic growth and the sustainable development of the logistics sector in selected Central and Eastern European countries from 2008 to 2024. The synthetic sustainability index captures both average effects and cross-country variation.

The results suggest that sustainability trade-offs arise mainly from scale-related effects of economic activity. At the same time, the impact of economic growth on sustainable logistics development varies across countries, with the most substantial impact observed in Slovakia. However, conditional analysis did not confirm that inflation or unemployment levels significantly altered this relationship.

Economic growth is not the only factor essential for sustainable logistics development. The sustainable development of the logistics sector depends on the business models and strategies adopted, as well as national regulations governing business activities. The limitations of this study relate to the use of aggregated sectoral data and the assumptions underlying the index construction. The obtained results should be interpreted as conditional statistical associations within a fixed-effects identification framework, rather than definitive evidence of causal relationships.

Further research could focus on microeconomic analyses, a dynamic approach, and expanding the geographic scope of the analyses.

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PHILOSOPHICAL ASPECTS OF MODERNITY ACCORDING TO LESZEK KOŁAKOWSKI. PROLEGOMENA

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Purpose: The aim of this article is a philosophical analysis of the condition of the contemporary human being in the context of modernism and postmodernism, with particular focus on the works of Leszek Kołakowski. In his writings, Kołakowski addresses key issues of freedom, individual identity, and meaning in the face of changing cultural paradigms. His reflections on the impact of political and intellectual systems on the individual reveal a deep concern for individual freedom within the context of dominant ideologies.

Methodology: The publication is theoretical in nature and is based on a literature review. The applied method allowed for the analysis of the current state of knowledge regarding the concepts related to the discussed issues. This not only enabled the definition of the scope of the discussion but also highlighted areas requiring further research. The analysis suggests possible directions for future studies and formulates open questions that may serve as a starting point for deeper reflection in subsequent works.

Findings: The publication highlights key issues related to the impact of modernism and postmodernism on the condition of the contemporary human being. It discusses the influence of these concepts on the process of shaping individual identity and subjectivity in the context of changing paradigms, the shift in the approach to issues of truth, identity, and power, the need for a balance between individual freedom and social structure, as well as the consequences of social responsibility in the context of individual freedom.

Social consequences: Both concepts have a crucial impact on the status of the individual and the quality of democracy. In a world where technology increasingly dominates human values, the lack of balance between these currents and the necessity of protecting human rights and the community can lead to the weakening of individual subjectivity and the deterioration of democratic standards. As a result, this may lead to the erosion of the foundations of democracy and an increase in the alienation of the individual in the face of technological and ideological dominance.

Originality: The publication attempts to analyze contemporary existential crises in the context of epistemological transformations that began in modernity and intensified in postmodernism. It offers a critical assessment of these processes, while also highlighting their mutual interpenetration and impact on contemporary culture and society.

Keywords: modernity, postmodernity, technology, freedom, democracy, autonomy, rationalism, relativism, technocracy, subjectivity.

Category of the paper: conceptual paper, viewpoint.

Introduction

The contemporary crisis of humanity, understood as a crisis of the human subject, manifests itself in the erosion of stable identity, axiological relativism, and dehumanization caused by the instrumentalization of the individual. From the perspective of modernity and postmodernism, this crisis evolves from the promise of the emancipation of reason to the deconstruction of all ontological narratives. Modernity, rooted in the Enlightenment concept of anthropocentrism, in its classical form constructs the human being as an autonomous, rational creator of history, striving for universal progress achieved through science and technology. The crisis reveals itself in the paradox of this vision: belief in linear development leads to mental enslavement under a totalitarian mindset, where the individual is reduced to a function within an ideological or economic machine. This is manifested today in technocratism, where the human being becomes a tool for optimization, subordinated to the logic of efficiency, leading to the loss of both freedom and identity (Bauman, 2006). Postmodernism, in turn, announces the "death of the subject" and grand narratives, questioning objective truth and, to some extent, invalidating its epistemological legitimacy, which once guaranteed the clarity of communicative intersubjectivity. This, in consequence, represents a kind of deconstruction of the humanistic foundations that once created a coherent ontological project (Lyotard, 1997). As a result of the influence of both narratives, the outcome is ethical relativism, fragmentation of identity, and a culture of simulacra, where values are contextually constructed, and consumerist egoism replaces the communal *telos*. Today, this manifests itself in identity politics, cultural divisions, media hyperreality, and moral nihilism, deepening alienation towards global capital, thus disconnecting the individual from authentic bonds, turning them into a cog in the global system, where the consumption of simulacra masks exploitation, amplifying loneliness and meaninglessness in the neoliberal world (Baudrillard, 2009). In this new reality, humanity faces the challenge of regaining authenticity and meaning, which can only be possible through the reconstruction of communal bonds. These bonds counteract the alienation of the individual and create space for reflection on the full potential of human subjectivity. In a globalized world, a person can find their place through constructive discourse that fosters mutual understanding, acknowledges differences, and builds a shared space for dialogue. Such a process becomes an essential counterbalance to technocratic instrumentalization, offering a space for reflection on the ontological foundations of human existence.

Cogito ergo sum

Leszek Kołakowski identifies the contemporary crisis of human nature as a profound alienation of man from an indifferent world, the loss of metaphysical meaning, and the destruction of humanistic foundations, an existential crisis resulting from the dominance and entrenchment of extreme rationalism in modernism and relativism in postmodernism. Kołakowski emphasizes the experience of “indifference”, understood as a specific foreignness of the external world to human needs. Although man possesses reason, he feels estranged, incapable of fully taming reality. This leads to a constant striving for myths and triggers an existential anxiety in man, revealing the need to ascribe meaning to reality through symbolic constructs, such as “guarantors of meaning” like religion, history, or progress, which ultimately prove to be illusions (Kołakowski, 1994). As a result, the human being loses the coherence of their identity, becoming a slave to their own illusions or relativistic irony. In Kołakowski's philosophical analysis, the ontological-axiological crisis of contemporary humanism manifests as a consequence of adopting Cartesian *cogito*, Enlightenment rationalism, and logical empiricism, (Kołakowski, 2005). These epistemological paradigms constitute the methodological-axiological core of Western European cultural identity, manifesting through the primacy of reason, the destruction of the authority of tradition, and the reduction of the religious dimension of existence, thereby determining the hierarchy of values in the modern era. Kołakowski is far from adopting an affirmative stance towards the values of technocratic culture, within which knowledge is legitimized not as an autonomous and autotelic activity aimed at discovering the meaning of existence, but as a tool subordinated to the rationale of practically transforming reality (Kołakowski, 2000). This process is carried out based on a specific concept of science, understood as a form of knowledge that abstracts from historical and psychological conditions, while systematically eliminating the axiological dimension from the description and interpretation of reality: “One is allowed to adopt such a stance, but one must not claim that it is anything other than a stance, that is, a certain evaluative perspective in which we place our surroundings; one must not, in particular, claim - this would contradict other fundamental assumptions of the positivist program - that there are non-relativistic values hidden within this stance, something that is valuable independently of human history, the state of needs, psychological dispositions, or arbitrary (in the logical sense of the word) decisions” (Kołakowski, 1966, p. 219). Revealing the threats to the status of contemporary man within the culture and social world, the philosopher undertakes an analysis of negative phenomena characteristic of both the modernist era and the postmodernist era, which stands in opposition to it as a critical reaction to the cult of modernity. Postmodernism, by particularly highlighting the ideas of pluralism, multiculturalism, and tolerance, shapes a paradigm of thinking that, despite its declared openness, leads to questioning the existence of universal and objective cognitive rules. The relativization of the criteria of knowledge and the undermining of the

possibility of establishing a universal concept of truth weaken the epistemological foundations of science, and consequently lead to the erosion of the authority of knowledge. In this sense, the postmodern affirmation of the multiplicity of perspectives and the equality of narratives not only abolishes the cognitive hierarchy but also creates space for radical relativism, in which truth loses its normative character and is reduced to a cultural or discursive construct, especially since: "If there are no universal human cognitive criteria, the only possible solution is to establish the validity of science through terror" (Kołakowski, 2009, p. 266). Postmodernism can be understood as an attempt to critically revise existing ways of perceiving and interpreting reality. It adopts an anti-rational approach to truth, manifested through randomness, discontinuity, disintegration, and the indeterminacy of the cognitive perspective. As a result of this approach to reality, the objectively formulated certainty based on universal principles and norms regulating human knowledge and action is called into question: "Husserl was convinced that the search for certainty is constitutive of European culture and that abandoning this search would be tantamount to the annihilation of that culture" (Kołakowski, 1991, p. 10). In postmodern thought, there is thus a rejection of the classical philosophical tradition, for which self-reflective consciousness is a fundamental instrument of the hermeneutics of reality and the recognition of the existential condition of the human being: "For quite some time, German thinkers have been teaching us that the human species has a natural "hermeneutic" tendency: that in everything it experiences, it almost instinctively seeks meaning" (Kołakowski, 2012, p. 133). The postmodern critique of the hierarchy of values in European culture shapes the meaning of human reality by emphasizing the "otherness" and "difference" of the world, (Rorty, 2009). The attempt to establish a universal ideal of values highlights the fragility of any certainty, indicating that claims to axiological stability are closely linked to specific historical and cultural conditions. Kołakowski points out that postmodern reflection questions the finality of philosophical thinking, suggesting that the systems of European philosophy which legitimize this certainty are the result of specific methods of thinking dominant in a given era, as well as particular assumptions about human nature. Postmodernism assumes that it is impossible to integrate different philosophical currents because there is no universal language that could objectively convey the meaning of concepts, and every use of a particular philosophical language always reflects a specific worldview (Kołakowski, 2012). Postmodernism emphasizes the impermanence and conventionality of all orders of meaning, axiological, methodological, and epistemological, undermining the belief in their universal and stable nature. In this framework, a particular type of existential consciousness emerges, within which the subject can attain the promise of freedom, authenticity, and agency by acknowledging the pluralism of perspectives and opening up to dialogue with the Other. This freedom is understood as emancipation from the dominance of totalizing meta-narratives of modernity, such as rationalism or the primacy of science, and the subject is constituted in relation to many competing discourses of power. In this view, the meaning of human existence and the order of values are not discovered or normatively

grounded, but are generated in the process of continuous confrontation between equal perspectives (Rorty, 2009). Dialogue and dispute do not serve an explanatory or teleological function here, but instead become a mechanism of continuous deconstruction of prevailing norms and meanings. This dynamic leads to the erosion of stable axiological foundations and, consequently, to the weakening of the subject's ability to make responsible choices, with the choice itself becoming illusory. The promise of autonomy, constructed in conditions of continuous deconstruction, then appears as fragile and illusory, because instead of allowing for conscious shaping of life, it reduces to a constant undermining of everything that could provide lasting meaning and a foundation for decisions. Dialogue, which "explains nothing", ceases to be a space for understanding and becomes a process of self-sustaining destabilization, in which freedom is reduced to a lack of commitment rather than to a conscious striving for truth, good, or community: "Man is a being constituted by thinking about himself; his effort should be aimed at achieving authenticity, shedding, to the extent possible, all forms of reification, all subjugation to external, 'thing-like' forms of existence" (Kołakowski, 2000, p. 29). From a postmodern perspective, this freedom, however, has an authentic character because it arises from the deconstruction of hierarchies and the affirmation of the multiplicity of voices, allowing one to avoid the illusion of the individual's autonomization. The subject does not regain autonomy in isolation, but in relationality, recognizing the difference of the Other as an equal element in the play of meanings. However, postmodernism does not actually advocate for the affirmation of the hierarchy of the Other's values; on the contrary, by consistently deconstructing hierarchies as arbitrary products of power and discourse, it reduces "respect" for the Other to a pluralistic tolerance of perspectives, rather than acknowledging their normative orders as superior. The Other is indeed included in the dialogue, but without granting their values a privileged status. Such a concept of freedom inevitably generates tensions, leading to accusations of its superficiality and limitations imposed by relativism. Negatively understood, "liberation from" norms does not translate into a positive "striving for" truth or community, but results in the fragmentation of identity, relativistic dispersion, and nihilistic emptiness. As a result, the subject, instead of genuinely regaining autonomy, falls into dependence on new, subtle forms of hegemony, concealed under the guise of pluralism, which undermines the very promise of reclaiming subjectivity. The subject ceases to be an ethical subject and becomes a carrier of narratives or a "text to be interpreted". This threatens its dehumanization, as it remains without a normative shield that could protect it from the hegemony of new forms of power (Žižek, 2008). Postmodernist reflection emphasizes that classical philosophy, which sought to achieve objective and rational knowledge of reality and assumed the existence of a universal truth, no longer meets the intellectual challenges of contemporary times. It is anachronistic and belongs to the past, because: "All metaphysical positions are equally good; I do not take any particular stance myself, I simply express the principle of tolerance, which, although commendable, is formal in nature and will never reveal, nor even inspire, any metaphysical idea. But by trying to uphold this principle while simultaneously sticking to

my particular point of view, I fall into inconsistency, since I then claim that my position is as good as any other, even though it is incompatible with any other” (Kołakowski, 2012, p. 121). Kołakowski emphasizes both the intellectual sterility of this position, as the principle of tolerance, while a valuable and desirable attitude, in this context takes on a formal character, contributing nothing new to the philosophical discourse, and reveals its inherent contradiction, how to reconcile this imperative of tolerance with the privileged epistemological position granted to it, while maintaining loyalty to one's own point of view. This paradox exposes the contradiction of postmodern relativism, which, while defending its doctrine, grants it epistemological primacy, the very existence of which it simultaneously undermines. This means that relativism, while attempting to eliminate dogmatism, itself introduces a dogmatic hierarchy. Moreover, this relativism, although freeing us from the shackles of rigid paradigms, does so at the cost of metaphysical grounding (Kołakowski, 2002). The human being, therefore, who constitutes the meaning of the world, operates in conditions of limited ability to rationally organize various spheres of life, where meanings are shaped randomly and dependent on the demands of culture. In postmodern thought, there is no universal transcendental criterion that constitutes and sustains the meaning of reality, because reality consists of many equal perspectives and “multiplicities of universes” (Lechte, p. 428). Furthermore, the meaning and significance of the world are constantly modified by cultural and civilizational changes, which undermines the permanence of any established values. Kołakowski notes that postmodernism's questioning of the objective validity of value systems leads to Weber's concept of *Entzauberung*, which constitutes the core of today's widespread discomfort in culture, and he wonders, “Where should we look for the sources of those aspects of modernity that make this discomfort particularly unpleasant?” (Kołakowski, 1999, p. 191). He notes that the valorization of diversity and difference, typical of postmodern thought, is simultaneously in contradiction with the doctrinal European paradigm that regards the individual as the fundamental measure of value and meaning, a paradigm that “created the idea of humanism in the form of faith in the inalienable value of personality” (Kołakowski, 1984, p. 21). Identifying postmodernism as a stage in the development of philosophical thought, the philosopher particularly opposes postmodernism's attempts to nullify the heritage of European philosophical thought by eliminating old philosophical questions, especially since “we have never stopped and probably will never stop asking such questions. We will never rid ourselves of the temptation to perceive the world as an enigmatic cipher, to which we stubbornly try to find the key, and moreover, we will persist in searching for that key. And from where does this highest legitimacy of the verdict, which forbids us from such searches, derive?” (Kołakowski, 2012, p. 139). Kołakowski observes that engaging with irresolvable philosophical questions constitutes the essence of the human being, who expresses their existence not in the calm of ready-made answers, but in the constant effort of updating and searching for the meaning of the world. Inert self-satisfaction emerges here as a dangerous factor in the destruction of civilization, not only in the sense of losing the significance of once-great ideas but also in the

erosion of community, because without the effort of seeking meaning, societies are doomed to fragmentation and cynicism. It thus becomes necessary to recognize a certain privileged cognitive perspective, expressed through the conscious acceptance or rejection of the axiological and methodological assumptions that shape the point of reference, and thereby the order of values. Adopting this perspective is a return to classical metaphysics, to its classic questions that touch the core of being, the meaning of existence, and the boundary of the knowable, and which constitute the ontological essence of humanity. From this perspective, good is not a subjective convention or an arbitrary norm, but a real realization of the fullness of existence; ethics is not a relative negotiation of values, but a hierarchy of virtues leading to the fullness of humanity; and science does not pretend to replace philosophy. Kołakowski reminds us that there is no philosophy completely devoid of assumptions, capable of revealing the objective, unreduced nature of human reality. Absolute postmodern relativism, which treats all values and positions as equivalent, leads to a cognitive illusion. By questioning the contingency of postmodern ideas, their affirmation of values based solely on a subjective hierarchy of preferences and the ambivalence of attitudes, Kołakowski also critiques the very notion of the era, drawing attention to its elusiveness and complexity, which cannot be reduced to a single, named framework. As he states, “No era and no civilization can conceptually identify themselves. Such identification can only be made once the era has passed into the past” (Kołakowski, 1999, p. 186). The philosopher starts with the fundamental epistemological assumption that no era or civilization is capable of adequate conceptual self-identification during its own duration. The participants of a given era remain inevitably immersed in the present, which sets the horizon for their thinking, judgments, and interpretations. Only from a historical perspective, possible after the departure of a given cultural formation, can a relatively coherent conceptual understanding of it be achieved. For this reason, any attempts to conceptually define the character of a given era should be considered problematic, even a terminological abuse, as they require a cognitive distance that is not yet accessible to historical subjects functioning within the same era. This inability arises from the fact that every era is based on a set of absolute, *implicitly* accepted axiological and cognitive assumptions that are not subject to reflection but function as self-evident elements of reality. It is these “self-evidencies” that constitute the internal order of the era, while simultaneously making it invisible to its participants, which is why we are fundamentally incapable of discovering the assumptions of our own era. As a result, historical subjects are unable to grasp the overall meaning of their own historical situation or define its identity in an adequate way, unless, as Kołakowski metaphorically puts it, the owl of Minerva has already flown out, meaning only when philosophical reflection becomes a *post factum* reflection (Kołakowski, 1999).

The Project of Modernity

In this broad context, modernity emerges as a particularly problematic category, as its essence is not a stable set of characteristics, but a dynamic tension between structure and evolution, between the affirmation of the existing order of the world and the need for its continuous transcendence. Modernity does not consist of a simple break with the past, nor its uncritical preservation, but rather a permanent dispute over the meaning of tradition, progress, and change. Kołakowski notes that “the conflict between the old-fashioned and the modern is undoubtedly eternal, and we will never get rid of it, as it expresses the natural tension between structure and evolution. Every society clearly needs both conservative forces and those that promote change, and one must doubt whether any theory could create good tools with which we could measure the relative strength of these opposing energies” (Kołakowski, 1999, p. 187). This tension constitutes both modern historical consciousness and the conflicts embedded in the very project of modern civilization. For this reason, the identification of any civilization is largely determined by its positioning in relation to the past. The past here is not merely a collection of historical facts, but serves a normative and interpretative function, establishing the framework within which cultural self-definition is possible. Disputes about the sources of European modern civilization, therefore, express deeper axiological tensions related to the question of continuity and rupture, heritage and innovation, tradition and emancipation. Kołakowski simultaneously emphasizes the arbitrary nature of attempts to conceptually identify the modernity of contemporary European culture. The lack of clear criteria for distinguishing its constitutive features means that concepts such as “modernity” or “postmodernity” function more as interpretative tools than as precise analytical categories. The philosopher's skeptical declaration that he does not know what postmodernity is or how it differs from modernity does not express cognitive helplessness, but rather a conscious critique of the ambition of philosophy attempting to capture the meaning of its own era in a final and unequivocal manner (Kołakowski, 1999). As a result, Kołakowski's reflection leads to the conclusion that modernity, like any other cultural formation, remains an open category, continually negotiated and historically variable. Attempts to define it definitively are doomed to incompleteness because they arise from the very reality they seek to describe. Thus, thinking about modernity becomes not so much a matter of definition, but a critical reflection on the limits of historical self-awareness.

One of the fundamental dimensions of modernity is the process of secularization, which, as Kołakowski emphasizes, leads not so much to the elimination of *the sacred*, but to its transformation. In *The Presence of Myth*, Kołakowski points out that the need for meaning, the absolute, and ultimate justification is not eradicated with the triumph of scientific rationality. On the contrary, myth, understood as a structure of meaning that gives coherence and sense to the world, remains a permanent element of human experience, even in the context

of modern secularization. Modernity, by proclaiming emancipation from myth, in reality, fails to free itself from it, but merely represses it to the unconscious sphere or transforms it into substitute forms (Kořakowski, 1994). As a result, this process leads to an existential crisis of meaning, which becomes one of the key elements of the contemporary human condition. The removal of *the sacred* as a universally binding point of reference results in the fragmentation of the experience of the world and a weakening of the normative foundations of morality. In *If God Is Dead*, Kořakowski formulates one of the most pressing questions of modernity: whether, in a world deprived of a transcendental foundation, it is possible to objectively justify good and evil. The philosopher does not offer simple answers but exposes the dramatic tension between the need for absolute norms and the awareness of their metaphysical uncertainty (Kořakowski, 1987). In this sense, the conflict between traditional Christian wisdom and the scientific view of the world is not limited to doctrinal dispute but concerns the very structure of human existence's meaning. Science, though highly effective in describing and explaining reality, is incapable of providing answers to ultimate questions that continue to demand answers. The repression of *the sacred* does not eliminate these questions but makes them more dramatic and devoid of clear solutions. Kořakowski points out that under conditions of secularization, *the sacred* returns in distorted forms, often as secular absolutes: political ideologies, utopias of progress, the cult of reason, or history. This phenomenon represents an attempt to compensate for lost transcendence, yet these efforts often lead to the absolutization of the *profane*, which in turn deepens the crisis of existential meaning rather than overcoming it. In response to this situation, European culture undertakes an effort to organize the axiological sphere, drawing on tradition as a relatively lasting resource of norms, behavioral patterns, and symbolic structures of meaning. Tradition, though no longer endowed with metaphysical certainty, still serves an orienting and stabilizing function, allowing for the preservation of the minimal conditions of moral order in a world affected by the crisis of *the sacred*. However, it does not provide a final solution to the problem of meaning, but rather stands as a testimony to the inescapable need to root human experience in something that transcends purely instrumental rationality. From Kořakowski's perspective, modernity thus appears as a formation marked by permanent ambivalence: on the one hand, the striving for emancipation from myth and transcendence, and on the other, the inability to function without the structures of meaning that myth and *the sacred* traditionally provided (Kořakowski, 1994). Philosophy is not a tool for ultimate resolution here, but a form of critical reflection on the tragic dimension of the modern human condition, in which the need for the absolute remains in irreconcilable tension with the experience of its absence. Tradition serves as a fundamental source of intellectual authority, enabling the preservation of cultural and normative identity. In Kořakowski's view, modernity, in its pursuit of rationalizing all dimensions of reality, gradually eliminates those elements of culture that cannot be fully justified by reason, thus leading to the weakening of the experience of *the sacred*. This process results in a crisis of meaning, understood as the loss of the metaphysical horizon within which human actions and

values could find ultimate justification. In response to this situation, cultural conservatism emerges as a stance affirming the significance of tradition and taboo as inalienable components of the moral order. Taboo does not function here as a manifestation of irrationalism or as a primitive prohibition, but as a primordial, ethical form of establishing boundaries, without which interpersonal relationships are subject to instrumentalization. Through the prohibitions sanctified by tradition, taboos sustain the awareness of the existence of the Other as a subject, toward whom absolute ethical norms apply. Kołakowski emphasizes that the fundamental values of European civilization, such as the inviolability of the right to life, the idea of human dignity, and personal rights, do not have ultimate justification within the framework of instrumental rationality. Their legitimacy is based on a metaphysical assumption about the inherent dignity of the human being, which is innate, independent of external conditions and circumstances, and cannot be reduced to the pure logic of means and ends. Their validity relies on prohibitions of an ‘irrational’ taboo nature, which, however, constitute the condition for the existence of a lasting moral order. Attempting to replace *the sacred* with secular absolutes proves to be dangerous and insufficient; it is a shortcut that leads to further erosion of meaning, revealing the limitations of the modern project of rationalizing culture, especially since: “In the normal sense of the word ‘rationality’, there are no rational reasons for respecting human life and personal rights, just as there are no rational reasons for the prohibition of eating shrimp by Jews, meat on Fridays by Catholics, or wine by Muslims. All of these are ‘irrational’ taboos” (Kołakowski, 1999, p. 200). The philosopher thus draws attention to the role of the sacred and taboo in maintaining moral order. The process of secularization removes *the sacred* from modern culture, but at the same time, it does not automatically eliminate the need to experience meaning or search for the absolute; it merely shifts this need to another order. Attempts to replace the transcendental foundations of normativity with secular “absolutes” prove insufficient, as they do not protect the dignity and inalienable value of the human person, nor its moral status. In this view, taboo serves as an essential element of moral order, defining the boundaries of permissible action and safeguarding social relations from instrumentalization, which can be seen as a reference to Kant's philosophy of morality: “Among all forms of practical knowledge, moral laws and their principles not only differ fundamentally from all others, which contain some empirical element, but the entire moral philosophy is entirely based on its pure part, and when applied to man, it borrows nothing from knowledge of his nature, but provides him, as a rational being, with *a priori* laws” (Kant, 2001, p. 12).

Leszek Kołakowski's reflections on contemporary civilization focus on the problem of shaping human subjectivity in the context of the increasing rationalization and secularization of culture. The philosopher notes that the dominance of instrumental rationality and utilitarian thinking leads to the reduction of the human being to the role of a social function or a carrier of specific utility. Such reduction weakens the normative foundations of the community, as it eliminates values that cannot be captured in terms of efficiency, but which are simultaneously essential for maintaining lasting human relationships. In this context,

Kołodowski emphasizes the importance of solidarity as a key element in the value structure of European civilization: “It is difficult to define what human dignity is; it is not an empirical discovery, but without it, we are in trouble when trying to answer a simple question: why is slavery wrong? Despite its closeness, the concept of human dignity is sufficiently adequate to address such a question” (Kołodowski, 1999, p. 216). Solidarity is, therefore, for Kołodowski not the result of individual interest or social agreements, but a primordial normative assumption that allows us to recognize the Other as a full moral subject. Without such recognition, the meaning of human personality fades, and social relations become subordinated solely to the logic of instrumental rationality (Król, 2016). Another important concept in Kołodowski’s reflections is responsibility, treated as a constitutive dimension of human subjectivity. Responsibility is not an addition to being human, something external to it, but a condition for the constitution of the moral subject: “The sense of responsibility, which cannot be entirely transferred to ready-made rules, yet is connected to values experienced as non-arbitrary (though historically and humanly rooted in their origin), is therefore an essential condition for a life in which reality appears meaningful, and the human individual as free” (Kołodowski, 2000, p. 172). It is precisely from the perspective of responsibility that the inalienable status of the person is revealed, a status that cannot be subordinated to either criteria of utility or the logic of rational management of social resources (Tischner, 1999). The condition for the survival of European civilization is, therefore, the affirmation of the inalienable value of the human person, understood as a permanent moral commitment, expressed in the idea of solidarity with others and in responsibility for the community of fate and the shared world. Without them, all institutions, laws, and social order lose their meaning, and moral norms become relative, subject to the whims of the moment or the will of authoritarian individuals (Varoufakis, 2024). The acceptance and affirmation of this assumption absolutizes the idea of humanity, which is not a function of utility or efficiency. Although this idea is an abstract and intellectual concept, it is exemplified in the form of very practical legal and social solutions, of which we are daily beneficiaries. Solutions such as dignity and the inviolability of every human being. Therefore, this abstract idea forms the basis and argument for the existence of a coherent and just community, without which social life would reduce to aimless drifting or selfish games of interests, where the triumph of social Darwinism as the prevailing ideology would be an inevitable consequence (Kołodowski, 1999). This concept, and precisely the recognition of the human person as an absolute value, allows European culture to maintain its durability and meaning, even in the face of crises that break the bonds with *the sacred* and weaken traditional structures of responsibility: “Humanity is not defined by specific markers distinguishing it from other species, but by participation in the realm of rational necessity, epistemologically expressed as a set of synthetic *a priori* judgments, as well as in the sphere of unconditional and compelling moral imperatives, which cannot be empirically established” (Kołodowski, 1984, p. 132).

Conclusion

The works of Leszek Kołakowski, through their deep analyses of cultural and philosophical phenomena, serve as a key point of reference for contemporary debates on individual freedom, particularly in the context of modernism and postmodernism. Kołakowski examines the dynamic transformations of contemporary culture and provides a keen diagnosis of their impact on human freedom and subjectivity. In the context of modernism, which emphasized faith in reason, progress, and individual autonomy, Kołakowski identifies the dangers arising from excessive technocratic dominance, which leads to the dehumanization of the individual, treated as a mere element of a larger machine. Kołakowski points to the necessity of critical reflection on this concept, questioning the true freedom of the individual in light of the growing role of technology and institutions, which increasingly shape its life. In the context of postmodernism, which undermines grand narratives, including the idea of progress and objective truth, Kołakowski highlights the relativity and contradictions of these assumptions. In postmodernism, where truth and identity become relative, and traditional structures of power and hierarchies are questioned, Kołakowski sees both an opportunity for liberation from the dominance of dogmatism and a danger of normative chaos. On the one hand, postmodernism creates space for individual freedom, but on the other, in the face of the crisis of stable values, it fosters the emergence of new forms of dependency and domination, which can evoke feelings of confusion and alienation. According to Kołakowski, freedom is not a fixed value or something given once and for all; it is a dynamic space that the individual must constantly shape, defend, and rediscover. Kołakowski draws attention to the fact that in a world full of contradictions, ideologies, and technological tools, the ability to think independently and make autonomous decisions becomes a challenge that cannot be ignored. In the context of a globalized world, where the boundaries between humans and technology are becoming increasingly fluid, Kołakowski poses fundamental questions about the balance between individual freedom and the demands of contemporary civilization. He argues that individual freedom should not be treated as something absolute, but as a space that must be protected from instrumentalization by technology, politics, and other dominant ideologies (Naim, 2022). Kołakowski's reflections on contemporary cultural challenges, especially in the context of the relationship between technology and humanity, serve as an important point of reference for current debates on freedom, responsibility, and subjectivity in the posthumanist era.

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ORGANISATIONAL READINESS FOR PROCESS AND DIGITAL TRANSFORMATION

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Purpose: This article presents the results of a multidimensional diagnosis of process maturity and organisational readiness for change in a regional passenger rail operator, using Koleje Wielkopolskie sp. z o.o. as a case study. The objective was to assess employees' process knowledge, the level of process standardisation and measurement, and to identify organisational barriers and the potential for organisational and digital transformation in the context of increasing competition in the Public Service Contract (PSC) market.

Methodology: Methodological triangulation was applied, combining a survey (N = 84), expert interviews, and diagnostic workshops. The research design was grounded in Business Process Management (BPM) principles and reference process maturity models. The analysis enabled a multidimensional assessment of process awareness, procedural formalisation, digitalisation level, and employee attitudes toward change.

Findings: The results indicate a medium–high level of process maturity, high employee process awareness, and strong declared readiness for change, alongside significant constraints in IT system integration, data quality, procedural coherence, and interdepartmental communication. A maturity gap was identified between dynamic operational growth and the formalisation and measurement of processes.

Practical implications: The study proposes key development directions, including system digitalisation and integration, structuring of process architecture, establishment of a coherent Key Performance Indicators (KPI) system, and creation of a permanent process improvement team. The findings provide actionable guidance for public transport organisations preparing to operate in a more competitive environment.

Originality/value: The study offers an integrated empirical assessment linking BPM maturity models with organisational readiness for change and technology readiness perspectives in the under-researched context of regional rail transport. It contributes to theory by highlighting interdependencies between process maturity, digital capability, and organisational readiness, and to practice by supporting evidence-based transformation and performance management in organisations facing competitive tendering.

Keywords: process maturity; readiness for change; Business Process Management (BPM); digital transformation; rail transport.

Category of the paper: Research paper.

1. Introduction

Today, rail transport constitutes one of the pillars of sustainable mobility in Poland and in the European Union. In recent years, rail has become a viable alternative to private car use and road transport, both for climate-related and cost-related reasons. However, the requirements of the European Green Deal, pressure to reduce emissions, and the rapid digitalisation of the sector mean that operators must simultaneously maintain service quality and improve organisational efficiency. This also applies to regional operators, which operate at the intersection of regional transport policy, passenger expectations, and the real costs of service provision.

The Polish passenger rail market is developing exceptionally dynamically. According to data from the Office of Rail Transport (UTK), more than 407 million passengers were transported in 2024, representing the best result in more than 20 years. At the same time, analyses based on the Passenger Transport Model forecast that by 2030 passenger numbers may increase within a wide range of between 11% and 37% (Krawiec, 2025). This growth has not occurred by chance; it has been achieved through the modernisation of railway infrastructure and rolling stock, improvements in travel standards, increased frequency of regional services, and the development of convenient interchange connections. At the same time, labour, electricity, fuel, and rolling stock maintenance costs are rising, while passengers increasingly expect efficient, predictable, and digitally enabled services. As a result, operators must improve resource planning and optimise rolling stock maintenance cycles.

Koleje Wielkopolskie sp. z o.o. is one of the strongest regional rail operators in Poland. The Company delivers services under a Public Service Contract (PSC) with the Self-Government of the Wielkopolska Region, which provides stable financing while simultaneously requiring cost transparency and performance accountability. After 2030, with the full implementation of the Fourth EU Rail Package (Directive 2016/2370/EU and Regulation 2016/2338/EU), the regional passenger transport market will become more open to competition. This means that existing “in-house operators” – such as *Koleje Wielkopolskie* – will have to compete for contracts in practice, rather than continuing to receive them through direct award procedures.

In this perspective, the structuring of organisational processes, the improvement of digitalisation, the preparation of facilities for the internal execution of rolling stock overhauls of the P4-level from 2026 (in Zbąszynek, Poznań and Wągrowiec), and the development of a performance measurement culture become critical. In order to address these challenges, it was necessary to assess process maturity across the dimensions of People – Processes –

Technologies, in order to determine whether the Company is ready for such a competitive leap and which elements require prioritised strengthening.

2. Organisational change and organisational maturity: concept, models and assessment

2.1. Organisational change

Changes occurring within organisations constitute an inherent element of their functioning and simultaneously represent some of the greatest challenges faced by contemporary organisations (Kulawik-Dutkowska, 2016). Organisational change in enterprises is often driven by environmental pressure arising from market competition and regulatory requirements. It may also be driven by technological pressure resulting from the obsolescence of technologies and solutions applied within the enterprise. Organisational change encompasses all transformations of the current state of various functional areas of an enterprise into a future state (Walas-Trębacz, 2009). The literature identifies several models of change management, among which one of the most frequently applied is Lewin's force field theory, which encompasses a three-stage change implementation process.

The process of organisational change should begin with the freezing of the current state of the organisation, followed by the introduction of planned changes. Only after these changes have stabilised should the organisation be refrozen (Johanne, 2025). According to Lewin, change occurs when the balance of forces acting on the organisation is disrupted such that forces driving change become stronger than forces maintaining stability (Lewin, 1947). The first phase, unfreezing, occurs when previously applied procedures and behavioural patterns lose their validity as a result of destabilisation, while change-orientated strategies gain prominence. The second phase, the implementation of the change, represents the decision-making process on which changes should be introduced into the organisation. Typically, a change has one or more initiators (change agents) who supervise its implementation. Once the change has been implemented and accepted, the organisation enters the third phase, refreezing. Refreezing refers to renewed stabilisation of the organisation through the establishment of new behavioural patterns and the introduction of new procedures (Kulawik-Dutkowska, 2016; Hussain et al., 2018).

In the field of change management, the literature also frequently refers to Kotter's eight-step model of change implementation. The first step involves establishing a sense of urgency for change. The second step assumes the creation of a guiding coalition, that is, a team responsible for leading the change. The third step comprises the development of a vision and strategy of change that define the direction of change. In the fourth step, the vision of change is communicated to the widest possible group of employees. The fifth step focusses on enabling

action in support of the vision of change by removing obstacles that hinder the implementation of planned changes. The sixth step assumes the generation of short-term wins resulting in visible improvements in organisational performance. In the seventh step, changes are consolidated and further developed through the modification or enhancement of procedures or rules that no longer align with the vision of change. The final step involves anchoring the changes and embedding them permanently in the organisational culture (Grzesiuk, 2007; Pollack, Pollack, 2015).

The sources of organisational change can be divided into two categories: internal sources, related to the organisation's operations and strategy, and external sources, resulting from changing market conditions (Kulawik-Dutkowska, 2016). Changes themselves may be classified as planned or unplanned, with the objective of adapting the organisation to changing external or internal conditions (Greenberg, Baron, 2010). Change may arise from a specific event or organisational need and may encompass the entire organisation or only part of it. Moreover, organisational change can be evolutionary or revolutionary in nature (Bukłaha, Cabała, 2022).

2.2. Awareness, readiness, and maturity in the context of organisational change

Awareness, in the context of organisational change, refers to the understanding of stakeholders of what change entails, including its expected outcomes and which elements of the organisation will be affected. Organisational awareness of the need for change constitutes the first stage of organisational transformation (Zine, 2025). Ready for change refers to the psychological and behavioural readiness of members of individual functional areas of the organisation to undertake change. Readiness encompasses, among others, beliefs, motivation and skills related to conducting change, as well as the resources that will be involved in its implementation (Caci et al., 2025). Maturity in relation to change denotes the organisation's ability to identify and adapt to change, as well as to manage it effectively. Organisational change maturity reflects the level of development of structures, processes, competencies, and organisational culture, and is most commonly described through maturity models that determine the ability to implement change in a repeatable manner (Silva, Mamede, Santos, 2025).

At the same time, numerous studies indicate that one of the most frequent causes of the failure of change initiatives is insufficient organisational preparation and the lack of an adequate diagnosis of the initial state (Burke et al., 2022). Of particular importance is the assessment of readiness for change, which is a construct encompassing both psychological aspects (attitudes, motivation) and structural aspects (procedures, competencies, processes) (Mladenova, 2022). Understanding these relationships forms the foundation for the effective design of transformation initiatives.

Organisational readiness for change can be considered at multiple levels within the organisation. Readiness may be related to an individual, a group of individuals, a department, or the organisation as a whole (Weiner, 2009). In the literature, readiness is also conceptualised in three perspectives. First, readiness is considered at the individual level, with reference to personal capabilities and self-efficacy. Second, readiness is understood as perceived organisational readiness for change, that is, the belief that the organisation is capable of implementing the planned changes. The third perspective refers to the actual readiness of the organisation to introduce change, namely its real capability to achieve the intended objectives and successfully complete the change implementation (Vakola, 2013). In the literature, organisational readiness for change is very often associated with related concepts such as organisational readiness and technological readiness. As noted by previous studies, there are significant similarities between organisational readiness for change and technological readiness, observable among both operational employees and administrative staff (Dönmez et al., 2020).

Organisational readiness indicates whether members of the organisation are prepared to implement the planned changes (Caci et al., 2025). The concept of Organisational Readiness for Change (ORC) comprises two dimensions: psychological readiness and behavioural readiness. The originator of this concept, B.J. Weiner, assumes that the organisation must be capable of implementing the planned change, while at the same time its employees must be aware of it and accept it (Weiner, 2020).

Psychological readiness encompasses the attitudes and beliefs of employees who will be directly or indirectly involved in organisational change. It assumes the mental preparedness of both operational and managerial staff for organisational transformation. Behavioural readiness, in turn, encompasses the intentions and actions of employees. In this context, organisational readiness for change denotes the preparation of organisational members to implement change based on proven methods supporting change implementation. Behavioural readiness also focusses on communication and the appropriate allocation of available resources in the context of organisational change implementation (van de Water et al., 2024; Tasleem et al., 2023).

Technological readiness, by contrast, refers to an organisation's ability to integrate and use new technologies. This capability arises from the ability to adapt to changing conditions in which the organisation operates, including technological conditions. Technological change is dynamic in nature, and an organisation seeking to adapt effectively should equip its employees with the necessary skills, knowledge, and tools that enable them to work with advanced solutions, including in terms of applied technologies (Jamil et al., 2025).

2.3. Organisational and technological Macromaturity models

In addition to the change management models discussed earlier – namely Lewin's force field theory encompassing a three-stage change implementation process, Kotter's eight-step model of change implementation, and Weiner's Organisational Readiness for Change (ORC)

model – the literature also presents other models of organisational readiness for change (Bukłaha, Cabala, 2022). The organisational readiness models described in the literature are summarised in Table 1.

Table 1.
Organisational readiness models

Author (year)	Model	Key characteristics
van de Water et al., 2024; Adelson et al., 2021	ORIC Model (The Organisational Readiness for Implementing Change)	– a questionnaire consisting of 12 items (7 items measuring motivation and 5 items measuring capability), assessed using a five-point Likert scale; – applied to assess organisational readiness for change implementation across two dimensions of change engagement, namely motivation and change efficacy.
Jaaron et al., 2022; Osolase et al., 2022	ADKAR Model (Awareness, Desire, Knowledge, Ability, Reinforcement)	– a five-stage model for implementing effective and sustainable change among employees, developed by J. Hiatt; – focusses on change at the level of individual employees, employee groups, or entire organisations; – assumes that the most critical stage of change is the awareness of employees of the need for change and that the organisation's role is to provide employees with access to knowledge and skills.
Suwanda, Nugroho, 2022; Jain, Kansal, 2023	McKinsey model (Model 7S / Structure 7S)	– a model developed by R.H. Waterman and T. Peters distinguishing seven elements divided into “hard” elements – the technical perspective of the organisation (strategy, structure, systems) – and “soft” elements – the social dimension of the organisation (shared values, style, skills, staff); – individual employee's skills developed with organisational support.
Chavan, Bhattacharya, 2022; Tarnoff et al., 2021	Kubler-Ross	– a model developed by E. Kübler-Ross comprising five emotional stages experienced by employees responding to organisational change; – based on the stages of denial (rejection of the fact that change is being implemented) and anger (awareness that change has commenced within the organisation), bargaining and depression (initial implementation of change) and acceptance (full organisational adoption of change).
Anderson, 2025	Knoster-Lippitt Model	– the model developed by Knoster and Lippitt is based on five elements: vision, consensus, skills, resources, and an action plan; – the absence of any of these elements may lead to difficulties in successful change implementation.
Wang et al., 2020	Model by T. Wang et al.	– measures readiness at both the individual and organisational levels and identifies interdependencies between them; – low readiness at both the individual and organisational levels indicates a dysfunctional phase (low employee engagement translating into low change effectiveness and limited value); – low organisational readiness combined with high individual readiness indicates an emergent phase (high initiative and effectiveness at the individual level, accompanied by a lack of organisational and structural support); – low individual readiness combined with high organisational readiness indicates a development phase (organisational structures support change implementation across departments, while individual engagement remains low); – high readiness at both the individual and organisational levels indicates a realisation phase (high change effectiveness and value resulting from strong engagement at both levels).

Cont. table 1.

Damschroder et al., 2022; Deshields et al., 2021	CFIR Model (Consolidated Framework for Implementation Research) Updated in 2022 to CFIR 2.0	– comprises 48 constructs (determinants) and 19 sub-constructs integrated within five main domains; – the main domains include: intervention characteristics and the level of implementation complexity; the inner context, referring to conditions within the organisation; the outer context, referring to conditions external to the organisation; characteristics of individuals, relating to employees involved in the implementation process, including their readiness for change; and the implementation process, encompassing activities and strategies undertaken throughout the change journey.

Source: his own elaboration.

The assessment of organisational readiness for change implementation can also be conducted using technology readiness models. The technology readiness models are presented in Table 2.

Table 2.
Technological readiness model

Author (year)	Technological Readiness Models	Characteristics
Yfanti, Sakkas, 2024; Salvador-Carulla, 2024; Straub, 2015; Lavin et al., 2022	TRLs Model (Technology Readiness Levels)	– assesses readiness for technological change implementation using a nine-level scale; – Level 1: observation of basic principles and research to understand the model and process; Level 2: concept of a new technology; Level 3: experimental proof of the technological concept; Level 4: laboratory validation of the developed technology; Level 5: testing of technology in a relevant environment; Level 6: prototype implementation of the technology; Level 8: deployment of technology in a commercial project; Level 9: fully mature technology; – the model assumes extension by two additional levels and the application of AI and ML solutions.
Pires et al., 2024	TRI2.0 Model (Technology Readiness Index)	– uses a five- or six-point Likert scale to assess 16 different elements grouped into four sub-dimensions (optimism, innovation, discomfort, uncertainty).
Khoza et al., 2024; Aljarrah et al., 2016; Xie et al., 2025	Technology Acceptance Model – TAM	– assumes an understanding of the factors that influence users' decisions regarding the adoption of a given technology; – defines the extent to which an employee believes that the implemented technology will improve work performance and the perceived ease of use; – The assessment may be conducted at the level of an individual employee, a department, or the entire organisation using a five-point Likert scale.
Kampa, 2023; Hutami et al., 2022; Larasati et al., 2017	Technology Readiness and Acceptance Model – TRAM	– integrates two approaches: the Technology Readiness Index (TRI) and the Technology Acceptance Model (TAM); – incorporates both the individual characteristics of users assessed in four dimensions (optimism, innovation, discomfort, and uncertainty) and the perception aspects of technology (perceived usefulness and ease of use).
(Díaz-Arancibia et al., 2024; Hradecky, 2022; Omonov, Ahn, 2025	Model TOE (technology, organisation, environment).	– focusses on assessing technological readiness (external and internal), incorporating both organisational aspects (enterprise structure and resources) and environmental aspects (environment and stakeholders of the organisation).

Source: own elaboration.

The reviewed models collectively indicate that technological readiness extends beyond the technical maturity of solutions to include user acceptance, organisational capabilities, and environmental context. This justifies the adoption of a multidimensional diagnostic perspective in the present study, integrating process maturity, organisational readiness for change, and digital enablement in order to capture the systemic conditions required for successful transformation in complex transport organisations.

3. Research methodology

3.1. Scope of the research

Dynamic changes occurring in the organisational environment – including increasing complexity of operational processes, pressure for efficiency, and the need for flexible responses to the requirements of customers and regulators – make the role of process management critical to maintaining competitiveness (Zaw, Huang, 2024).). The literature emphasises that organisations with a high level of process maturity achieve greater operational efficiency, better service quality, and greater adaptive capacity (Sanford et al., 2024). However, the implementation of process management and the development of process maturity require not only structural changes, but also an adequate level of employee awareness, leadership engagement, and an organisational culture conducive to continuous improvement.

In the context of the above challenges, it is justified to conduct research that enables the following (Table 3):

- the diagnosis of the' level of process knowledge of the employees, which constitutes the foundation for the implementation of process management and the development of a process-orientated culture,
- the determination of the level of process maturity, allowing for the assessment of the degree of standardisation, stability, and efficiency, as well as comparison with reference models applied in managerial practice,
- the assessment of readiness for change, which constitutes a necessary condition for the effective implementation of organisational transformations,
- the integration of perspectives of different stakeholder groups, enabling the consideration of potential discrepancies between the perception of processes by operational employees, process owners, and senior management.

Table 3.
Methodology

Research variable	Definition	Indicators/questions	Scale/ Source of data	Methods
Process awareness	Degree of employee' understanding of the flow and interdependencies of key organisational processes	Declared process knowledge and ability to identify inter-process interdependencies (interviews)	Likert's scale1-5; qualitative data	Survey, interview
Process maturity – formalisation	Degree of existence, currency, and actual application of procedures	Accuracy of procedures; implementation in practice	Likert's scale1-5;	Survey, workshop
Process maturity – standardisation	Consistency of process execution across organisational units	Based work on standards vs. hidden knowledge	Likert's scale1-5; qualitative data	Survey, interview
Process maturity – measurement	Degree of utilisation of process performance indicators	KPIs; measurement repeatability; assessment approach (formal vs. intuitive)	Likert's scale1-5;	Survey, workshop
Process maturity – governance	Scope of monitoring and control of process execution	Controls regularity; responsibility of process owners	Likert's scale1-5;	Survey
IT support for processes	Level of integration and use of IT systems in process execution	Level of system integration; using alternative tools (Excel); satisfaction form operating systems	Likert's scale1-5;	Survey, interview
Data quality	Accuracy, completeness, and accessibility of process data	Assessment of data quality in key operational areas	Likert's scale1-5;	Survey
Ready for change – psychological	Employee' attitudes, motivation and acceptance of change	Openess to changes; declared need to develop competencies	Likert's scale1-5;	Survey
Ready for change – Behaviour	Propensity to undertake improvement initiatives	Participation in bottom-up initiatives; declared improvement activity	S Likert's scale1-5; qualitative data	Survey, interviews
Process and digital competencies	Level of competencies in BPM and IT tools	Demand for training; identified competency gaps;	Likert's scale1-5; qualitative data	Survey, interviews
Interdepartmental communication	Effectiveness of information flow between organisational units	Communication quality assessment; availability of shared data	Likert's scale1-5;	Survey
Organisational stability	Continuity of human resources and organisational experience	Staff turnover rate	Secondary data	Documents analysis

Source: own elaboration.

The application of methodological triangulation – surveys, expert interviews, and diagnostic workshops – enables the acquisition of an in-depth multidimensional diagnosis which, in line with the recommendations of the literature, increases the reliability of conclusions and allows the complexity of organisational phenomena to be captured (Vivek et al., 2023).

These studies are therefore justified both theoretically, as a contribution to the development of knowledge on process maturity and readiness for change, and practically, by providing organisations with data necessary for the design of effective transformation programmes.

The objective of the conducted research was a complete diagnosis of the knowledge of the organisational processes, the level of their maturity, and the organisation's readiness to introduce change. The methodology was developed based on the assumptions of Business Process Management (BPM) and process maturity assessment models such as BPMM (Lopes, Guerreiro, 2023), CMMI (Fabbro, Tonchia, 2021) and SPICE (ISO/IEC 15504).

Methodological triangulation was applied (Stamenkov, 2023), combining quantitative and qualitative approaches to improve the reliability and depth of interpretation of the findings. The study was designed according to the recommendations for organisational diagnosis and change assessment (Tabash et al., 2023).

3.2. Surveys

The survey constituted the primary quantitative method, allowing the measurement of the level of process awareness, subjective assessment of process maturity, and declared readiness for change. The questionnaire was developed according to the principles of measurement instrument design (Olawale et al., 2023) and included closed-ended questions, including items based on a five-point Likert scale.

The sample had a purpose-random character and comprised 84 representatives from various organisational areas of the analysed entity. Electronic data collection enabled efficient statistical analysis, including response distributions and the identification of respondent clusters that differed in their level of readiness for change.

3.3. Expert interviews

Expert interviews, conducted in a semi-structured format, enabled the deepening of the survey findings and a better understanding of the contextual determinants of processes. This methodology is consistent with the research approach applied in organisational analyses, in which expert knowledge and the interpretative nature of qualitative data play a significant role (Pregoner, 2024). The interviews focused on identifying key process-related conditions within the company that had been identified in the quantitative research.

3.4. Diagnostic workshop

The workshops were conducted as a form of participatory organisational diagnosis, in line with the assumptions of a dialogical and stakeholder-engaging approach (Kurek et al., 2023). The workshops served to triangulate quantitative and qualitative findings, conduct a maturity assessment using a reference model, identify change priorities, and determine implementation barriers.

The assessment process applied a five-level process maturity model encompassing criteria such as standardisation, efficiency, governance, accountability, and continuous improvement. The results were analysed through moderated discussion, which allowed the development of a shared diagnosis of process awareness and maturity, as well as readiness for change.

4. Research results

The study was conducted in May 2025 in the form of an electronic survey and workshops. A total of 84 employees representing 24 administrative functional areas of the Company participated – ranging from operations and vehicle maintenance, through finance and controlling, to HR, IT, logistics, warehousing, and public procurement.

An analysis of the length of service of the employees indicated that 42.9% of respondents (36 individuals) have been employed by Koleje Wielkopolskie for more than ten years, a further 22.6% for between three and five years, and only a small number for less than two years. At the same time, 90.5% of respondents possess more than ten years of professional experience, including experience gained outside the Company. This indicates that the study covered a stable workforce with a strong understanding of organisational realities and the capacity to provide reliable assessments of its processes.

4.1. Process awareness

The awareness of the process of the employees was assessed as very high. More than 92% of respondents declared that they understand the course of key business processes well or very well – including the planning and delivery of transport services, rolling stock and infrastructure maintenance, warehouse management, dispatching, and settlements.

This result indicates a strong embedding of operational knowledge among employees and a high level of practical competencies. At the same time, qualitative data revealed a limited ability to perceive processes from a systemic and interdepartmental perspective. Process knowledge is fragmented and strongly embedded within individual organisational units, which hampers the development of a coherent process architecture and the identification of inter-process dependencies. This represents a typical profile of an organisation that has developed

very rapidly and has only subsequently caught up with organisational structures after the implementation of new responsibilities.

4.2. Data quality and IT support for processes

The assessment of data quality revealed significant variation across functional areas. Higher scores were recorded in highly formalised areas (including public procurement, rail safety, and sales), while lower scores were observed in areas directly related to operational activities, in particular rolling stock maintenance, inspection planning, and parts traceability. Nearly 72% of respondents positively evaluated data in the areas of public procurement, rail safety, and sales; however, information critical from an operational perspective performed significantly worse, including rolling stock inspection and overhaul plans, parts traceability, and data on the production capacity of maintenance facilities. The auditors conducting the study directly linked this to the limitations of the current ERP system, Quatra Max.

The digitalisation of processes proved to be the weakest element. Only 36.9% of employees stated that their area of work is fully supported by an integrated IT system, although as many as 85.7% nevertheless use Quatra Max. However, only 20% of users declared satisfaction with this system. Moreover, 89.3% of respondents admitted that they rely on their own Excel spreadsheets and additional ad hoc data compilations, which leads to the emergence of parallel, unsynchronised sources of information. The report explicitly indicated that further development of the current ERP is poorly justified and that the Company should implement a new, modern, and integrated system, as well as complete the implementation of electronic document management (EDM) and the employee portal.

The widespread use of alternative tools (spreadsheets, local data compilations) indicates a low level of informational integration and the presence of fragmented data sources. To increase the analytical precision of the diagnosis, the identified IT limitations can be differentiated into four interrelated dimensions: system functionality, interface usability, integration architecture, and data governance.

From the perspective of system functionality, the current ERP solution does not sufficiently support several operationally critical processes, including rolling stock inspection and overhaul planning, parts traceability, production capacity planning of maintenance facilities, and flexible generation of management reports and KPIs. As a result, employees compensate for missing or rigid system functions by maintaining parallel spreadsheets and local datasets, which weakens process transparency and increases operational risk.

In terms of interface usability and user experience, the low level of declared user satisfaction (20%) suggests that the system does not adequately support efficient daily work, particularly in data entry, retrieval, and reporting. Limited user-friendliness and restricted analytical capabilities further reinforce the tendency to bypass the system through manual tools, despite the formal availability of the ERP platform.

From an integration architecture perspective, Quatra Max operates largely as a silo application rather than as an integrated process platform. The lack of seamless integration with systems supporting maintenance management, crew scheduling, electronic document management, and analytical reporting prevents end-to-end process visibility and constrains the organisation's ability to synchronise operational planning across functional areas.

Finally, in the area of data governance, fragmented data ownership, inconsistent data standards, and the absence of a single authoritative data repository limit the reliability, completeness, and timeliness of operational information. These shortcomings directly affect parts traceability, maintenance planning accuracy, and the credibility of performance measurement, thereby reducing the organisation's informational maturity.

The convergence of these four dimensions explains why incremental development of the current system is assessed as insufficient and why the recommendation for the implementation of a new, integrated ERP-class solution is grounded not only in user dissatisfaction but also in structural limitations of the existing digital architecture.

4.3. Process formalisation, standardisation, and measurement

From the perspective of process maturity, data on procedures and measurement are also of key importance. A total of 56% of survey respondents confirmed that procedures in their areas are up to date and applied; however, as many as 34.5% admitted that despite being current, they are not used in practice. The findings illustrate that in recent years organisational development has progressed more rapidly than formal internal regulations, and that part of the work is performed based on experience. Process planning in 77% of cases is based on solutions developed during the Company's growth and on employees' knowledge, rather than on uniform standards. In the area of control, 75% of respondents indicated that regular control based on procedures is in place; however, a gap emerges in measurement: 2% of processes are not measured at all, almost 30% are assessed intuitively, and only approximately one third make use of clearly defined KPIs.

The audit report indicates that the first elements of a coherent KPI system are already in place within the Company. In the operations division, key operational indicators are monitored on an ongoing basis, including:

- train punctuality, currently maintained at 95% against a target of 96%,
- alignment of the schedule with passenger needs, assessed at 65% against an expected level of 75%,
- working inventory reserve, currently at 8% for diesel multiple units (DMUs) and 2% for electric multiple units (EMUs), compared with targets of 12% and 10%, respectively,
- the coverage ratio for the demand for the traction crew, currently 88% against a planned level of 110%.

In the areas of procurement and environment, indicators related to order timeliness, number of bids, inventory levels, implementation of the environmental plan, and the number of non-conformities are applied. In the HR department, staff turnover is monitored, among other indicators, – this rate amounted to 5.1% in 2024, which indicates a very stable form of employment and working conditions within the Company.

4.4. Organisational Readiness for Change

The declared readiness for change was assessed as high. Respondents demonstrate openness to process improvement and a clear need to enhance competencies, particularly in the areas of process management and IT tools. The high correlation between declared openness and readiness for change confirms the consistency of employee' attitudes and their adaptive potential. The self-assessment conducted between 14 and 21 May 2025 indicated that the workforce is open to change, but expects training support. More than 88% of respondents declared a need to develop process-related competencies, 65% expect training in process management, and 44% in the use of IT tools supporting such management. At the same time, numerous bottom-up individual improvement initiatives are observed in practice, which indicates a strong potential for the introduction of a culture of continuous improvement. The report also emphasised that the correlation between general openness to change and organisational readiness for change amounted to 0.72, indicating that employees' declarations are consistent with their actual attitudes.

Additionally, the report noted that the Company maintains a very stable level of employment – in 2024, the staff turnover rate amounted to only 5.1%, which is significantly below the threshold considered safe in the rail transport sector. With a total workforce exceeding one thousand employees, this provides a solid foundation for change implementation, while simultaneously increasing responsibility for systematic training: with low turnover, new competencies must be developed internally rather than relying on the inflow of ready-made specialists from the labour market. This applies in particular to the areas of IT, working inventory management, and data analytics, where the largest capability gaps were identified.

Against the background of the above data, weaker areas should also be noted: IT (limited system functionality and reliability), investments and improvements, and interdepartmental communication. In this respect, nearly 40% of employees assessed information flow across the organisation as unsatisfactory. Auditors indicated that the absence of regular interdepartmental meetings and the lack of a central, up-to-date data repository may contribute to limiting the potential for further growth in passenger numbers and more effective planning of rolling stock utilisation.

A more detailed analysis indicates that communication deficiencies are not uniform across the organisation but are concentrated in selected cross-functional processes requiring tight coordination between multiple organisational units. In the area of rolling stock maintenance

and inspection planning, limited data integration and delayed information exchange between operations, maintenance, and logistics constrain the timely alignment of vehicle availability with traffic plans and workshop capacity. Manual reconciliation of schedules and technical data increases the risk of planning inconsistencies and reactive decision-making.

In crew scheduling and operational planning, restricted real-time visibility of rolling stock readiness and fragmented data sources hinder the synchronisation of vehicle deployment with crew availability, which reduces planning robustness and operational flexibility.

Within procurement and spare parts logistics, insufficient feedback loops between maintenance units and purchasing functions affect demand forecasting, parts traceability, and inventory optimisation, leading to longer replenishment cycles and reduced transparency of material consumption.

Finally, in the domain of investment and capacity development, the lack of systematically shared operational performance data limits the ability to align long-term infrastructure and workshop expansion decisions with actual utilisation trends and future service growth scenarios.

These communication failure points illustrate that the identified weaknesses primarily affect end-to-end process coordination rather than isolated functional performance, thereby constraining further progress toward higher levels of process maturity and integrated process governance.

4.5. Organisational constraints and Risises

Key developmental barriers include a low level of integration with the IT system, limited operational data quality, insufficient standardisation of procedures, and inadequate interdepartmental communication. These constraints may significantly affect the organisation's ability to further scale its operations and implement advanced digital solutions.

The synthesised findings indicate a medium–high level of process maturity, along with a clearly observable gap between operational maturity and systemic and informational maturity. The organisation demonstrates high adaptive potential; however, its full exploitation requires the structuring of the process architecture, data integration, and the strengthening of measurement and governance mechanisms.

5. Conclusions

Koleje Wielkopolskie, a regional public rail operator in the Greater Poland (Wielkopolska) region of Poland, has currently achieved a medium–high level of process maturity. Its foundations consist of a stable and experienced workforce, well-functioning transport operations processes, high service quality and safety, and a well-established market position

within the region. At the same time, the organisation has entered a phase in which the previous “organic” mode of development – based on employee’ experience and flexible responsiveness – will no longer be sufficient to maintain competitive advantage after 2030, when PSC services will be awarded through competitive tenders.

5.1. Discussion

The findings confirm that the analysed organisation is positioned at a medium–high level of process maturity, which is consistent with the characteristics of organisations experiencing intensive operational growth, while not fully systemically formalised. The high level of employee’ process awareness indicates a strong embedding of practical knowledge and the effective functioning of informal coordination mechanisms. From the perspective of process maturity models (BPMM, CMMI, SPICE), such a profile corresponds to a transitional stage between managed and defined maturity, where processes are operationally stable but not yet fully standardised and informationally integrated.

At the same time, the observed fragmentation of process perceptions confirms observations reported in the literature that process knowledge in functional organisations is often local and silo-based in nature, which limits the ability to manage processes end-to-end. This phenomenon hampers the development of a process architecture and the implementation of advanced performance measurement mechanisms, which are prerequisites for progress to higher levels of process maturity.

A significant area of constraints remains the IT support of processes and data quality. Decomposing the IT-related constraints into functional, architectural, usability, and governance dimensions allows a more granular interpretation of the organisation’s digital maturity. While operational readiness and employee competencies are relatively advanced, the digital infrastructure lacks the modularity, interoperability, and data discipline required for scalable process orchestration and evidence-based performance management, which is consistent with maturity models emphasising the co-evolution of processes, information architecture, and governance mechanisms. The low level of system integration and the widespread use of alternative tools indicate a discrepancy between the operational maturity of the organisation and its digital maturity. These findings correspond to the assumptions of technology readiness models (TOE, TRAM), which emphasise that even high organisational readiness does not automatically translate into technology absorption capability if the information infrastructure and system architecture are not coherent. In this sense, the analysed organisation demonstrates characteristics of cultural and competence readiness while simultaneously facing technological barriers.

In the area of process formalisation and standardisation, a typical of growing organisations is observed between the dynamics of development and the currency of internal regulations. The dominance of tacit knowledge- and experience-based practices supports short-term flexibility but limits scalability, repeatability, and process transparency in the long term.

From the perspective of process management theory, the absence of clearly defined process owners and an inconsistent KPI system hinders the transition from functional to process-orientated management.

The high level of declared readiness for change, confirmed by the correlation between attitudes and developmental intentions, is consistent with the concept of Organisational Readiness for Change. The organisation exhibits both a psychological component (acceptance, motivation) and a behavioural component (bottom-up improvement initiatives), increasing the likelihood of successful change implementation. At the same time, employment stability strengthens the potential for the accumulation of organisational knowledge, but requires conscious investment in systematic competence development.

At a synthetic level, the findings indicate the existence of a maturity gap in three dimensions: operational, systemic, and informational. The organisation has achieved a high level of operational stability; however, the integration of processes, data, and technologies remains insufficient in the context of future competitive requirements. In line with the BPM literature, further growth in efficiency and adaptive capacity requires a shift from local improvements to systemic management of process architecture, performance indicators, and data.

The findings also confirm the validity of applying methodological triangulation in organisational diagnosis. The combination of quantitative and qualitative data allowed the identification of discrepancies between declared assessments and the actual mechanisms of process functioning, thus improving the validity of the interpretation. In this sense, the study makes a methodological contribution to research on process maturity and readiness for change in public transport sector organisations.

The results obtained are consistent with earlier studies that indicate that the success of process transformation depends not only on technology but also on organisational culture, competencies, and managerial coherence. In the analysed case, the key challenge is not the initiation of change, but rather its coordination and embedding in durable management mechanisms.

5.2. Integration of results

Data triangulation involved the comparison of findings from surveys, interviews, and workshops. This approach enabled mutual validation of observations, identification of discrepancies between employee' perceptions and senior management's assessment, and the development of a multidimensional view of organisational processes.

Integration was based on comparative logic (Kumar et al., 2022), which made it possible to develop a comprehensive diagnosis and recommendations aimed at increasing process maturity and readiness for change.

5.3. Research limitations

Despite its comprehensiveness, the methodology has certain limitations:

- self-assessment in the survey may generate cognitive biases, such as confirmation bias or the halo effect,
- expert interviews may be affected by respondents' subjectivity and power asymmetry, influencing the freedom of expression,
- group workshops may amplify dominant voices, which is consistent with the group conformity effect described in the literature (Janis, 1982),
- the results reflect the state of the organisation at a given point in time and may change in line with environmental dynamics.

Acknowledging these limitations is essential for the appropriate interpretation of the findings and their generalisation.

5.4. Research implications

5.4.1. Theoretical implications

The conducted study contributes to the literature on:

- process management, by confirming the importance of combining quantitative and qualitative methods in assessing process maturity,
- organisational diagnosis, by indicating the role of triangulation as a tool integrating diverse stakeholder perspectives,
- readiness for change, by supporting research emphasising that readiness is a multidimensional construct, dependent on both structural and psychological factors.

The study also confirms observations reported in the literature that perception of processes varies according to organisational role and experience (Mladenova, 2022).

5.4.2. Practical implications

The research findings have significant practical relevance:

- for senior management, they enable the identification of areas requiring improvement and the adjustment of process structures,
- for process owners, they provide data on process effectiveness and the degree of standardisation, which is crucial for planning improvement initiatives,
- for project teams, they help identify barriers to change implementation and determine the level of readiness of individual employee groups,
- for the organisation as a whole – they constitute a starting point for building a programme for the development of process maturity and a culture of continuous improvement.

The necessity of ERP replacement results not only from low user satisfaction but from cumulative structural limitations across functional coverage, interface usability, integration architecture, and data governance, which jointly prevent the establishment of a reliable single source of truth and effective end-to-end process management.

The key actions should proceed in three directions. First, digitalisation and system integration, including the replacement of current ERP-class software with a scalable solution integrated with systems supporting transport planning, train crew working time scheduling, rolling stock maintenance and inspections, electronic document management (EDM), and the employee portal – in order to eliminate duplicate records maintained in Excel and to ensure a single version of the truth for data.

Second, the standardisation and structuring of processes combined with the actual application of procedures, so that every activity has a clearly defined owner, performance indicator, and improvement cycle, and newly employed staff can be incorporated according to a uniform framework.

Third, the establishment of a single and coherent KPI system that refers to four stakeholder groups: passengers (punctuality, comfort, access to information), the transport authority (delivery of operational work, costs), employees (training, system access, service time) and the company's governing bodies (rolling stock efficiency, maintenance costs, resource use).

At the same time, based on the collected research results, it is recommended to establish a permanent process improvement team (e.g. a Lean Process Care Team) which – leveraging the high readiness of the Company's employees for change – would collect ideas from organisational units, structure them, and implement them in short iterative cycles. Such a solution would reduce the barrier of "lack of time for improvements" reported in surveys and interviews.

The implementation of these steps will enable the Company to optimise maintenance cycles financially and operationally (especially after the launch of in-house P4 overhauls from 2026), improve cost transparency and make better use of rolling stock, and above all – to enter the era of a competitive PSC market as an operator that is both process- and technology-ready. In recent months, the Company has already taken a significant step towards improving communication between organisational units and functional areas by changing its organisational structure. The integration of functional areas within divisions is an important measure to strengthen cooperation. Furthermore, the ongoing expansion of the IT division creates an opportunity to tailor IT processes more closely to organisational needs, improve their governance, and enable the modification or acquisition of IT tools supporting the operations of such a dynamically developing carrier in subsequent periods. However, it should be remembered that further areas still require continuous development, as after 2030 the selection of an operator will increasingly depend not only on price, but also on the ability to provide reliable reporting of quality and punctuality, rolling stock readiness, and transparency of maintenance costs. All three elements can only be achieved if processes are documented,

automated, and measured, and if data originate from a single, coherent system. Otherwise, even a carrier that is currently well evaluated may lose to an entity that is more structured in terms of both internal communication and cost management. This constitutes a real strategic risk for the Company

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MANAGEMENT OF ANIMAL TRANSPORTATION WITH REGARD TO ANIMAL WELFARE AND WORKER SAFETY

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Purpose: This paper aims to analyze livestock transport management, with a focus on minimizing animal stress and ensuring the safety of personnel involved in the process. The study examines key factors affecting animal welfare, including transport duration, environmental conditions, vehicle design, loading and unloading procedures, and personnel competence, while addressing associated occupational hazards.

Design/methodology/approach: A comprehensive literature review was conducted using PubMed, Web of Science, Scopus, and Google Scholar. Out of 130 relevant full-text publications, 41 key sources were selected for detailed analysis. Hazards were categorized by transport mode—road, rail, sea, and air—using risk assessment methods based on hazard severity and duration to prioritize interventions. Practical and organizational strategies for reducing stress and injury risk were synthesized from empirical studies and EU regulations, including Regulation (EC) No 1/2005.

Findings: Extended transport duration, limited access to water and feed, insufficient space, inadequate ventilation, and improper handling during loading and unloading were identified as primary stressors for animals and major occupational hazards for workers. Risk assessment highlighted highest-priority hazards, such as dehydration, pathogen exposure, and extreme environmental conditions. Implementing optimized transport routes, appropriate vehicle design, well-trained personnel, and real-time monitoring systems significantly improves animal welfare and reduces occupational risks.

Research limitations/implications: The study is based on literature and the EU regulatory context, which may not fully reflect practices in other regions. Future research should include field studies, real-time monitoring data, and evaluation of novel transport technologies to further refine welfare and safety strategies.

Practical implications: Adopting structured transport management practices enhances animal welfare, reduces economic losses, and improves workplace safety. Recommendations include route optimization, proper ramp design, adherence to space requirements, staff training, and real-time monitoring of transport conditions.

Social implications: Improved transport practices support societal expectations regarding animal welfare, contribute to public health through reduced zoonotic risks, and encourage responsible corporate and regulatory practices.

Originality/value: This paper integrates risk assessment with practical management solutions, offering a holistic approach to animal transport that simultaneously addresses welfare and occupational safety. It is valuable to farmers, transport companies, animal welfare authorities, and policymakers.

Keywords: animal transport, animal welfare, occupational safety, risk assessment, transport management.

Category of the paper: Literature review; risk assessment study.

Introduction

In 2022, a total of approximately 1.6 billion live sheep, cattle, poultry, and pigs were transported for commercial purposes within the European Union and beyond its borders by road, sea, rail, and air (European Commission, 2023). Long-distance animal transport is largely driven by economic factors, but it is increasingly the subject of discussions regarding animal welfare. Transport-related losses, including mortality, injuries, and reduced product quality, generate measurable economic costs for the livestock sector (Erzurum, Yilmaz, 2018). Contemporary transport methods have been highlighted as potential sources of stress and numerous hazards for animals (Broom, 1986; Christensen et al., 1994). This issue attracts the attention not only of animal welfare organizations and activists but also of supply chain participants, including farmers, slaughterhouses, and transport companies (Appleby et al., 2008). Increasing attention is also being paid to workers involved in the transport process, such as drivers, animal attendants, and personnel responsible for loading and unloading. These individuals often have direct contact with animals, which entails risks of injury during handling, stress from responsibility for animal welfare, and physical strain due to challenging environmental conditions.

Effective transport management enables the identification of issues within transportation processes and the implementation of solutions that provide tangible benefits. The competencies of managers play a crucial role, both in strategic planning and operational decision-making. Animal transport management encompasses a range of activities, from transport planning and selection of appropriate vehicles to the application of methods tailored to the needs of live cargo (Faucitano, Lambooi, 2019). Unlike goods, animals are susceptible to stress and injury, particularly during prolonged journeys, which requires adherence to proper practices and high handling standards. Therefore, effective transport organization entails simultaneously ensuring animal welfare and the safety of personnel who interact with them (Budzik, Budzik, 2019).

As public awareness grows, increasing attention is being paid to the conditions under which animals are transported. In European Union policy, animal welfare has been recognized as a priority area within the framework of the European Green Deal. Nevertheless, animal transport continues to involve numerous stress-inducing factors, occurring both during the

journey and during loading and unloading, stages particularly critical in terms of injury risk and behavioral disturbances. In recent years, technological progress has been made, replacing outdated and often non-ergonomic solutions with more advanced systems designed to enhance animal comfort and safety. However, despite these improvements, existing EU regulations still lag behind current scientific knowledge and transport practices. Updating these regulations is necessary to more effectively minimize stressors and reduce the risk of compromised animal welfare during transport (Giangaspero, Turno, 2024).

Animal welfare during transport is regulated under EU law. The primary legal act is Regulation (EC) No 1/2005 (EC, 2005). According to Article 1, this regulation concerns the transport of live vertebrate animals within the Community. Its main objective is to prevent injury and unnecessary suffering during transport. The regulation also aims to limit long-distance transport whenever possible and to ensure animal welfare both during the journey and upon its completion.

Despite extensive research on animal welfare during transport, existing studies predominantly focus either on animal-related stressors or on occupational risks for workers. There is a lack of integrated analyses that simultaneously assess animal welfare hazards and corresponding risks to transport personnel across different transport modes using a structured risk assessment framework.

The aim of this study is to conduct a comprehensive analysis of livestock transport management, with particular emphasis on animal welfare and the safety of personnel involved in the transport process. The analysis includes identifying key factors affecting animals' comfort, health, and behavioral responses during transport, as well as assessing hazards specific to different modes of transport (road, rail, sea, and air). The study also seeks to propose practical organizational and technological solutions, as well as operational procedures, that can effectively minimize animal stress and reduce the risk of injuries and occupational strain among personnel responsible for handling animals.

Effective management of livestock transport including optimized route planning, appropriate vehicle conditions, access to water and feed, and qualified workers leads to a significant reduction in physiological and psychological stress in animals, as well as a decrease in the risk of injury and overexertion among transport workers

Methods

The literature review was conducted following a structured search strategy. Searches were performed in the PubMed, Web of Science, Scopus, and Google Scholar databases. The literature search covered publications available from database inception until August 2025, with the final search conducted in August 2025.

The following keywords and phrases were used: “animal welfare”, “transport stress”, “behavioral stress indicators”, “animal transport management”, “loading and unloading procedures”, “worker safety” “injury risk”, “injury minimization”, “transport condition monitoring”, “ventilation and temperature in transport”, “animal transport space”, “transport route planning”, “animal rest and breaks”, “human–animal interactions during transport”, “protective equipment for workers”, “impact of transport on animal condition”, “economic loss reduction”, “innovative logistics solutions”, and “livestock transport organization”. Logical operators (“AND”, “OR”) were applied to combine keywords, and query syntax was adapted to the advanced search capabilities of each database.

The initial search yielded approximately 600 records. After removal of duplicates, titles and abstracts were screened for relevance, reducing the number of publications to 200. Full-text screening was then performed. Publications were excluded if they were not directly related to livestock transport, animal welfare, or worker safety, or if they demonstrated insufficient methodological quality.

Methodological quality was assessed based on commonly accepted criteria for narrative reviews, including clarity of study objectives, appropriateness of study design, transparency of methods, adequacy of sample description, and consistency between results and conclusions. Studies lacking sufficient methodological transparency or presenting anecdotal or non-verifiable data were excluded. Following this process, 130 full-text articles were assessed in detail, of which 41 key publications were ultimately included in the review and formed the basis for the synthesis of findings.

To enhance transparency and focus on the most relevant evidence, a final set of 41 key publications was selected using a qualitative, multi-criteria relevance assessment. Publications were considered “key” if they demonstrated strong methodological rigor, addressed both animal welfare and worker safety in livestock transport, provided findings applicable across different transport types, and offered clear practical or managerial guidance. Studies that met the inclusion criteria but had a narrower thematic scope, less methodological transparency, or limited applicability to transport practice were retained as supporting literature but were not classified as key publications.

The selected publications were categorized into the following thematic areas: animal welfare during road, rail, sea, and air transport; stress indicators and animal behavior during transport; safe loading and unloading procedures; transport management and route planning; vehicle design; ventilation; space allocation for animals; and worker safety and ergonomics in transport operations.

Inclusion criteria for publications were as follows:

- Publications must directly address animal welfare, stress reduction, and worker safety in the context of livestock transport.
- Original scientific research, review articles, and book chapters containing reliable and verifiable data.
- Full-text availability to allow detailed analysis of research methodology and results.

Given the heterogeneity of study designs, animal species, and outcome measures, no meta-analysis was conducted. Therefore, conclusions are based on qualitative synthesis, and results are described using cautious language (e.g., “the literature suggests” or “the literature indicates”) rather than implying statistical significance.

The findings were thematically organized to enable a comprehensive discussion of practical solutions, procedures, and management strategies aimed at minimizing animal stress and reducing the risk of injuries among personnel involved in transport operations.

2.1. Risk assessment procedure

The risk assessment procedure applied in this study consisted of four main stages: hazard identification, hazard characterization, exposure assessment, and final risk characterization. A key element of this analysis was the evaluation of potential impacts of identified hazards on individual animals. To quantify risk, the concept of magnitude was used, which combines the severity of the hazard (Severity) and the expected duration of its impact (Duration) according to the formula (Marahrens et al., 2011; Mueller-Graf et al., 2007):

$$\text{Magnitude} = \text{Severity} \times \text{Duration}$$

Each hazard identified in the literature was assigned Severity and Duration values on a 1-5 scale, following established protocols in animal welfare studies (Marahrens et al., 2011; Mueller-Graf et al., 2007). The resulting magnitude values enabled the ranking and prioritization of hazards, allowing the study to focus preventive measures on those with the greatest potential impact on animal welfare and worker safety.

Before applying this procedure, the population under analysis was defined carefully, taking into account the variability in transport methods, journey durations, and environmental conditions, such as microclimate, which can vary significantly across Europe (Marahrens et al., 2011). This structured approach provided a transparent and replicable framework for assessing risks across road, rail, sea, and air transport of livestock.

Results

Animal welfare risk assessment was conducted to identify and classify hazards across different modes of livestock transport. Hazards were evaluated based on severity (1-5) and duration (1-5), and a magnitude score ($\text{Magnitude} = \text{Severity} \times \text{Duration}$) was calculated to quantify their potential impact. Hazards with higher magnitude scores indicate a greater potential impact on animal welfare.

3.1. Road transport

Table 1 presents the identified hazards during road transport of livestock and their corresponding severity, duration, and magnitude scores. Prolonged journey duration and limited access to water and feed have been identified as key welfare risk factors during road transport (Buckham-Sporer et al., 2023). Severity refers to the intensity of the negative effect on animal welfare, while duration reflects how long the animal is exposed to hazard. The magnitude score combines these two parameters, allowing for prioritization of the most critical hazards that require immediate attention or intervention.

Table 1.
Animal welfare risk assessment during road transport

Hazard category	Severity (1-5)	Duration (1-5)	Magnitude (S × D)
Insufficient ventilation	4	4	16
Inadequate space	4	4	16
Long transport duration	4	5	20
Lack or limited access to water and feed	5	5	25
Improper handling during loading/unloading	4	3	12
Poor animal condition prior to transport	4	4	16
Introduction of pathogens	5	4	20
Inadequate rest periods	3	4	12

Source: Own research.

3.2. Rail transport

Table 2 summarizes hazards associated with rail transport, including notes on specific conditions that may exacerbate these hazards. This overview enables comparison of the relative impact of different hazards and helps identify areas where management or infrastructure improvements are most needed.

Table 2.
Animal welfare risk assessment during rail transport

Hazard category	Severity (1-5)	Duration (1-5)	Magnitude (S × D)	Notes
Insufficient ventilation	3	4	12	Rail cars usually have ventilation, but with high animal density it may be insufficient
Inadequate space	3	4	12	Space is limited, especially for long-distance transport

Cont. table 2.

Long transport duration	4	5	20	Rail covers long distances, which may extend journey times
Lack or limited access to water and feed	5	4	20	Supplying water and feed in rail cars is more difficult than in trucks and requires special organization
Improper handling during loading/unloading	4	3	12	Loading/unloading at rail terminals can be stressful and requires trained staff
Poor animal condition prior to transport	4	4	16	Animals in poor condition cope worse with transport
Introduction of pathogens	4	4	16	Long journeys in closed wagons increase the risk of disease spread
Inadequate rest periods	4	4	16	Long rail routes require well-planned stops and rest periods for animals

Source: Own research.

3.3. Sea transport

Table 3 shows hazards occurring during sea transport. Due to longer journey durations and the unique challenges of marine conditions, additional factors such as ship motion, vibrations, and limited veterinary access are included (Navarro et al., 2018). The table highlights both the severity and duration of each hazard, supporting a targeted approach to risk mitigation.

Table 3.*Animal welfare risk assessment during sea transport*

Hazard category	Severity (1-5)	Duration (1-5)	Magnitude (S × D)	Notes
Insufficient ventilation	4	4	16	Ventilation in closed containers or decks may be insufficient with high animal density
Inadequate space	4	4	16	Limited space in containers or on deck can restrict animal movement
Long transport duration	5	5	25	Sea voyages often last several days or weeks, increasing stress and health risks
Lack or limited access to water and feed	5	5	25	Requires automatic systems or regular delivery; organizational errors may cause dehydration or starvation
Improper handling during loading/unloading	4	3	12	Loading onto and unloading from ships is stressful and requires trained personnel
Poor animal condition prior to transport	4	4	16	Animals in poor condition tolerate long sea journeys worse
Introduction of pathogens	5	4	20	Closed containers and long transport promote disease spread
Inadequate rest periods	4	5	20	Long journeys require systematic rest and monitoring; lack of quick stops increases risk
Ship motion and vibrations	4	5	20	Prolonged rocking may cause seasickness, weakness, and stress
Variable climatic conditions	4	4	16	Extreme temperatures, humidity, and wind can worsen welfare
Isolation and limited veterinary care	5	4	20	Lack of rapid intervention in case of illness or injury increases risk

Cont. table 3.

Environmental contamination	4	4	16	Ammonia, moisture, and dust promote disease and respiratory irritation
Ship noise	3	5	15	Continuous engine and pump noise induces chronic stress
Risk of marine accidents	5	2	10	Ship failure, fire, or storm pose high risk, though rare

Source: Own research.

3.4. Air transport

Table 4 provides an assessment of hazards during air transport. Even though flights are generally shorter, factors such as cabin pressure changes, noise, and limited access to feed and water can have significant impacts on animal welfare. The magnitude scores facilitate identification of the most critical stressors during air transport.

Table 4.*Animal welfare risk assessment during air transport*

Hazard category	Severity (1-5)	Duration (1-5)	Magnitude (S × D)	Notes
Insufficient ventilation	4	3	12	Cargo holds and containers must be properly ventilated; risk increases if air conditioning fails
Inadequate space	4	3	12	Air containers restrict movement; stress increases on long flights
Long transport duration	3	4	12	Flights are shorter than sea or rail transport, but terminal waiting and transfers extend total time
Lack or limited access to water and feed	5	3	15	No water or feed can be given during flight; proper preparation before and after is essential
Improper handling during loading/unloading	5	3	15	Handling at airports and during loading onto aircraft can be stressful
Poor animal condition prior to transport	5	3	15	Animals in poor condition are at higher risk of flight-related complications (stress, respiratory issues)
Inadequate rest periods	3	3	9	Flights are usually short, but lack of rest before and after affects welfare
Pressure changes and stress	5	4	20	Cabin pressure changes, take-off, landing, and turbulence can cause stress, respiratory problems, and pain
Aircraft noise	4	4	16	Engine noise during take-off, landing, and flight induces chronic stress
Temperature and humidity in cargo hold	4	4	16	Improper control can lead to overheating or chilling
Isolation and lack of veterinary care during flight	5	3	15	Lack of immediate veterinary intervention increases risk of complications

Source: Own research.

3.5. Hazard categorization across transport modes

The assessment of hazards across all transport modes (Tables 1-4) allowed classification into three priority levels based on the calculated magnitude scores. This categorization provides a structured overview of which factors most significantly threaten animal welfare during transport and which require the highest level of attention from both regulatory and operational perspectives.

The highest-priority hazards, with magnitude scores ranging from 20 to 25, primarily involve threats to animals' basic physiological needs and factors related to transport duration. These include insufficient access to water and feed, extended travel times, exposure to pathogens, inadequate rest periods, motion and vibration during sea transport, and pressure changes during air transport. Such hazards are capable of causing severe physiological disturbances, compromising health, and in extreme cases, resulting in mortality. Immediate mitigation measures are therefore essential to prevent serious welfare impairments.

Hazards classified as high-priority (magnitude 16-19) largely relate to environmental conditions, including ventilation, temperature, humidity, limited space, animal health status prior to transport, and noise exposure. Although these factors may not lead to immediate life-threatening consequences, cumulative exposure can result in significant stress, dehydration, respiratory problems, or thermoregulation disturbances, particularly during longer journeys.

The medium- and low-priority hazards, with magnitude scores of 15 or less, encompass improper handling during loading and unloading, minor space restrictions, and less severe noise exposure. While individually these hazards are less critical, they may amplify the effects of higher-priority hazards, especially for vulnerable animals such as older, sick, or mobility-impaired individuals. Rare hazards, with magnitude scores of 10 or lower, should be addressed through emergency protocols and contingency planning.

This hazard categorization enables the prioritization of preventive and corrective measures, with particular attention to high-impact hazards in long-distance transport modes such as sea and road, where access to essential resources and veterinary care is critical. In shorter transport journeys, such as road and air, ensuring proper ventilation, adequate space, and minimizing stress during handling are key to maintaining animal welfare. The results are consistent with EFSA (2022), which emphasizes that welfare impairments intensify with transport duration and the accumulation of stressors. Effective risk management therefore requires not only well-designed transport infrastructure, but also competent personnel trained in monitoring animal condition, controlling microclimate, and applying appropriate handling techniques.

Discussion

The conducted studies on animal welfare risk assessment during transport allow for a comprehensive identification and classification of hazards depending on the mode of transport. The results presented in Tables 1–4 indicate that different transport modes are associated with distinct sets of risks, which vary in terms of severity, duration of exposure, and calculated hazard magnitude. This analysis enables the prioritization of hazards and the identification of critical points that require immediate intervention or improvement of transport practices.

Our study provides new insights into the comparative magnitude of risks across different transport modes, which has not been systematically quantified in previous research. This contributes original knowledge by ranking hazards according to their severity and potential impact on both animal welfare and worker safety.

4.1. Road transport

In the case of road transport, the highest magnitude values (20–25) were obtained for hazards such as lack of access to water and feed (25), prolonged travel (20), and introduction of pathogens (20). These results confirm that the basic physiological needs of animals and the duration of transport are key factors for animal welfare. These hazards can lead to serious physiological disorders, dehydration, loss of condition, and, in extreme cases, animal mortality, which aligns with EFSA (2022) observations emphasizing that longer transport times intensify the negative effects of stress and the accumulation of stress-inducing factors. Studies assessing the combined effects of transport duration and rest periods confirm that inadequate recovery time exacerbates welfare deterioration during road transport (Meléndez et al., 2020).

Additionally, high magnitude values (16) were recorded for hazards such as insufficient ventilation, limited space, and poor condition of animals prior to transport. Although these factors do not directly threaten life, their cumulative impact leads to chronic stress, respiratory problems, and thermoregulation disorders, especially during long journeys (Cockram et al., 1996; Grigor et al., 2001; Gerritzen et al., 2013).

4.2. Rail transport

In rail transport, similar hazards were identified, though with slightly lower severity for ventilation and space (magnitude = 12). Long railway journeys increase the risk of stress related to travel duration and limited access to water and feed (magnitude 20), as well as the risk of pathogen transmission and animal fatigue (magnitude 16). These results indicate that the organization and infrastructure of rail transport—including proper ventilation, access to water and feed, and stop planning—are critical for animal welfare (EFSA, 2022; Schwartzkopf-Genswein et al., 2012).

4.3. Maritime transport

Maritime transport is characterized by the largest number of high-priority hazards (magnitude 20-25), including prolonged journeys, lack of access to water and feed, ship vibrations and rolling, introduction of pathogens, lack of veterinary care, as well as pressure changes and stress during air transport. Specific maritime conditions, such as ship motion, vibrations, variable climatic conditions, and limited access to veterinary care, are particularly significant. These findings confirm earlier observations by Padalino (2015) and Padalino et al. (2018), indicating that prolonged travel in confined spaces increases the risk of disease and deterioration of animals' physical condition.

4.4. Air transport

Air transport is characterized by shorter travel times, but a high level of stress related to pressure changes (magnitude 20), engine noise (magnitude 16), lack of access to water and feed, and limited veterinary care options (magnitude 15). In poultry, pre-slaughter transport and handling under high temperature conditions further exacerbate physiological stress responses and welfare impairment (Vieira et al., 2024). These results suggest that even a short journey can lead to significant physiological and psychological stress if transport conditions are not properly controlled (Duncan, 2002; Appleby et al., 2008; EFSA AHAW et al., 2022).

4.5. Comparison of hazards across transport modes

The comparative analysis (Section 3.5) shows that the most critical hazards concern factors fundamental to animal survival: access to water and feed, transport duration, introduction of pathogens, limited rest periods, and environmental factors specific to the transport mode, such as ship motion or airplane pressure changes. Transport distance and exposure to adverse environmental conditions have been shown to directly affect transport-related mortality, particularly in poultry, where longer journeys are associated with increased losses (Vecerkova et al., 2019). High-priority hazards (magnitude 16-19) mainly relate to environmental conditions, including ventilation, temperature, humidity, limited space, and noise, which cumulatively affect animal health. Medium- and low-priority hazards (≤ 15) primarily include improper handling during loading and unloading, minor space restrictions, or noise on ships.

Our results highlight specific quantitative differences in hazard magnitude between transport modes, providing new evidence that maritime transport presents the highest cumulative risk, while air transport, despite shorter durations, still imposes substantial physiological stress. This distinction adds a nuanced understanding to the existing literature.

4.6. Impact of transport on animal welfare and worker safety

The transport of farm animals involves numerous stress-inducing factors that affect both animal welfare and the safety of the workers handling the transport. During transport, animals experience both physiological and psychological stress, resulting from factors such as vehicle movement (acceleration, braking, turning, uneven road surfaces), noise, vibrations, and limited space (Schwartzkopf-Genswein et al., 2012; Padalino, 2015; Padalino et al., 2018; Appleby et al., 2008). The movement of the vehicle, including acceleration, braking, turning, and vibrations, contributes to stress responses in animals and affects their balance and physiological stability during road transport (Randall, 1992). Driver behavior and driving style further influence stress responses in transported animals by affecting the intensity and frequency of vehicle movements (Peeters et al., 2008; Santurtún, Phillips, 2015).

Although aspects of psychological stress, such as limited space, noise, or vehicle movement, are recognized, these indicators were not systematically included in the formal risk assessment. Current frameworks focus mainly on physical and biological stressors, which limits a complete understanding of transport's impact on animal welfare. Immunological indicators have long been proposed as sensitive markers of stress in animals, although they are rarely incorporated into routine transport risk assessments (Siegel, 1985). Incorporating measurable psychological stress indicators in future risk assessments could provide a more comprehensive evaluation of hazards and enable more effective mitigation strategies.

Prolonged exposure to these factors leads to fatigue, dehydration, weakened immune function, and health problems, including increased susceptibility to disease (Goetz et al., 2023). Physiological responses to transport stress, including changes in cortisol levels, heart rate, and production parameters, have been documented in livestock exposed to transport-related stressors (Hong et al., 2019). Animals in poor physical condition prior to transport are particularly vulnerable to the negative effects of transportation and handling them presents additional risks to workers who must lift or support them during movement (Lambooi, 2024; Mobo et al., 2010; Barneo-Alcántara et al., 2021).

Improper handling of animals during loading and unloading increases the risk of injuries, pain, and panic among the animals (Lambooi, 2024; Appleby et al., 2008). For workers, such situations mean a higher likelihood of kicks, crushing, musculoskeletal strain, and operational accidents. Additionally, limited space in the vehicle increases the risk of collisions between animals and injuries, thereby exposing workers to further hazards (Appleby et al., 2008; EFSA AHAW et al., 2022).

Prolonged journeys and insufficient rest breaks result in cumulative fatigue and stress for both animals and workers, increasing the likelihood of errors and road or operational accidents (Schwartzkopf-Genswein et al., 2012; Padalino, 2015; Padalino et al., 2018). Lack of water and feed weakens animals, which can lead to aggressive behavior toward handlers and requires

workers to exert additional physical effort under challenging conditions (Pagliasso et al., 2023; Appleby et al., 2008).

Table 5 presents the main hazards to animals during transport along with the corresponding risks to workers, taking into account physical, biological, and ergonomic-psychological factors.

Table 5.

Main Hazards for Animals During Transport and Corresponding Risks for Workers

Hazard Category	Description of Hazard for Animals	Corresponding Risks for Workers
Insufficient ventilation	Inadequate air exchange leads to overheating, heat stress, and exposure to harmful gas compounds (e.g., ammonia, hydrogen sulfide)	Risk of fainting, dehydration, exposure to high temperatures, and harmful gas compounds (e.g., ammonia, hydrogen sulfide)
Limited space	Restricted space prevents normal animal behavior, increasing the risk of injury and stress	Increased risk of kicks, crushing, and difficulty maneuvering during loading and unloading
Long transport duration	Greater fatigue, stress, dehydration, and prolonged exposure to adverse environmental factors	Higher physical workload, prolonged exposure to environmental factors (e.g., noise), driver fatigue (risk of accidents)
Lack or limited access to water and feed	Dehydration, weakness, reduced welfare, and in extreme cases, death	Need for worker intervention under difficult conditions; risk of aggression from weakened or stressed animals
Improper handling during loading/unloading	Injuries, pain, panic, and severe stress	High risk of physical injuries (kicks, strikes, crushing), musculoskeletal overload, and workplace accidents
Poor condition of animals prior to transport	Increased susceptibility to disease and transport-related stress	Higher risk of exposure to zoonotic diseases; need to lift weakened animals (risk of musculoskeletal injuries)
Pathogen introduction	Possible infection before or during transport	Risk of zoonotic infections; work in conditions of increased biological hazard
Inadequate rest periods	Increased fatigue and risk of health disorders	Worker fatigue, higher likelihood of errors, and increased risk of traffic or operational accidents

Source: Own research.

The risk analysis presented in Table 5 emphasizes that improving transport conditions, proper management of travel time, ventilation, space, access to water and feed, and staff training is crucial not only for reducing animal stress and injuries but also for minimizing the risk of accidents and overexertion among workers (Gerritzen et al., 2013; EFSA AHAW et al., 2022; Lambooij et al., 2024).

Appropriate transport procedures, including safe loading and unloading, real-time monitoring of animal condition, and the use of personal protective equipment by workers, create an integrated approach that ensures the safety and welfare of all participants in the transport process.

4.7. Minimizing animal stress and worker risk

The study results emphasize that effective transport management includes route planning, optimization of travel time, provision of rest breaks for animals, and monitoring of environmental conditions in the vehicle, including temperature, humidity, and ventilation (Lambooij et al., 2024).

Safe loading and unloading require the use of ramps with appropriate slopes, minimal step heights, and high side barriers, as well as bedding, which reduces the risk of slips and injuries for both animals and workers (Warris et al., 1991; Goumon et al., 2013; Grandin, 1990). Experimental studies have shown that ramp angle, bedding type, and surface condition significantly affect animal movement, stress responses, and ease of handling during loading and unloading (Garcia, McGlone, 2014). Animals should be transported in groups consistent with their herd instincts, and handling should be calm, predictable, and free of sudden stimuli (Grandin, 1982).

Monitoring the health status of animals before and during transport, removing weakened or sick individuals from long-distance transport, and ensuring access to water and feed are essential for protecting animal welfare and minimizing risks to workers (EFSA AHAW et al., 2022; Gerritzen et al., 2013). High worker competence, regular training in safe animal handling, and the use of protective equipment reduce the risk of injuries, physical overexertion, and exposure to pathogens.

These results confirm our initial hypothesis that effective management of transport conditions significantly reduces both animal stress and worker risk.

4.8. Relevance of findings for practice and regulation

The conducted risk assessment indicates that systemic factors—transport duration, access to resources, environmental conditions, and staff competence—have the greatest impact on animal welfare and worker safety. These findings confirm the necessity of incorporating these elements into regulations, such as Council Regulation (EC) No. 1/2005, and transport practices, including route planning, optimized loading, adequate ventilation and space for animals, and real-time monitoring of conditions (EC, 2005).

Moreover, hazard prioritization enables the effective targeting of preventive and corrective actions, both in long-distance transports (maritime, road), where access to water, feed, and veterinary care is critical, and in short-distance transports (road, air), where proper ventilation, space, and minimizing stress during loading and unloading are essential (EFSA, 2022; Nielsen et al., 2011).

The analysis also highlights the crucial role of qualified personnel who can assess animals' fitness for transport, apply proper loading techniques, and monitor the microclimate as well as early signs of stress. An integrated approach, combining appropriate infrastructure, operational procedures, and staff competencies, effectively protects animal welfare and reduces the risk of injuries to workers. Additionally, it contributes to economic benefits by minimizing animal losses and improving workplace safety (EFSA AHAW et al., 2022; Lambooi et al., 2024).

Future research should focus on testing interventions to reduce stress in specific transport modes, evaluating the effectiveness of training programs for personnel, and developing real-time monitoring technologies to further enhance animal welfare and worker safety.

Conclusions

The study showed that maritime transport is associated with the highest cumulative risk, whereas air transport, despite its shorter duration, induces a high level of stress in animals. Comparative analysis revealed that basic physiological needs and transport duration affect animal welfare across all types of transport, while specific hazards, such as pressure changes and noise in air transport, were also identified. These conclusions are consistent with earlier welfare assessments emphasizing transport as a critical risk period for farm animals (Warriss, 1998).

Effective transport management including optimized route planning, appropriate vehicle conditions, access to water and feed, and qualified workers significantly reduces both physiological and psychological stress in animals as well as the risk of injury and overexertion among transport workers. Prioritization of hazards enables targeted preventive and corrective actions, which has practical implications for transport organization and regulatory compliance.

The variation in hazard magnitude between transport types highlights the importance of considering specific stress-inducing factors when assessing animal welfare and occupational risk for workers. Improving transport conditions also brings economic benefits by reducing animal losses and workplace accidents.

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ANALYSIS OF THE RELEVANCE OF WARREN BUFFETT'S VALUE INVESTING STRATEGY IN DIFFERENT MARKETS – A LITERATURE REVIEW

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Purpose: The purpose of this paper is to systematically evaluate the relevance and adaptability of Warren Buffett's value investing strategy across global markets through a comprehensive literature review.

Design/methodology/approach: A systematic literature review was performed using academic databases (Google Scholar, Scopus, university repositories). Keywords included "Warren Buffett", "value investing", "Graham's strategy", "Piotroski's F-score" and "fundamental analysis", combined with market-specific terms. Selected peer-reviewed empirical studies testing Buffett-inspired fundamental strategies in equity markets were analysed and synthesised by strategy components, performance measures and contextual factors.

Findings: Buffett's strategy, integrating value screening with quality assessment, generates significant excess risk-adjusted returns in many markets, especially emerging ones (Brazil, Indonesia, India). Performance improves with local adaptations (e.g., sector medians, adjusted ROE thresholds) and quality criteria (high ROE, low debt, economic moats). Effectiveness is cyclical and weaker in efficient developed markets during periods like the "value winter" or crises (e.g., 2020 pandemic). In emerging markets, part of the alpha may reflect liquidity risk premiums rather than pure mispricing.

Research limitations/implications: Limitations include varying study comparability, recent publication bias (post-2018 dominance) and potential overrepresentation of positive results. Future research should track performance as emerging markets mature and examine impacts of passive investing on value/quality premiums.

Practical implications: Investors should apply Buffett's principles globally but customise criteria to local conditions. Prioritising business quality and moats reduces value traps and enhances resilience across cycles.

Originality/value: This is the first systematic comparative review addressing the transferability of Buffett's strategy between developed and emerging markets, identifying behavioural/risk determinants and emphasising contextual adaptation.

Keywords: value investing, Warren Buffett, fundamental analysis, market efficiency, emerging markets.

Category of the paper: literature review.

1. Introduction

Warren Buffett, chairman and chief executive officer of Berkshire Hathaway, is widely considered one of the most successful investors in history. His remarkable long-term success has sparked intense debate about the universality of his investment strategy. Buffett's philosophy, which combines value investing principles, a deep understanding of business, and a long-term perspective, has gained a large following around the world. However, despite its widespread popularity, the adaptation of this approach to different market conditions, time periods, and regulatory structures remains the subject of intense academic research.

In numerous empirical studies covering emerging and developed markets, value investing approaches modelled on Warren Buffett's strategy generally generate excess returns compared to market benchmarks. Dantas Neto (2013) report that Buffett's portfolio in Brazil outperformed both passive and active funds, while Martin and Puthenpurackal (2008) note that Berkshire achieved an annualised return of 11.14% compared to the S&P 500 index. In Indonesia, Srikanth and Soekarno (2024) document a cumulative return of 1381.72% over 10 years, with a Treynor ratio of 14.27. Similarly, Xiao and Arnold (2007) report annual rates of return close to 19.7% in the UK market. Many studies also indicate that portfolios constructed using key value indicators – such as price-to-earnings, price-to-book, book-to-market and F-score – deliver better or positive risk-adjusted returns. Several studies indicate that combining these ratios with measures of financial strength improves performance, particularly for small- and mid-cap stocks. Adaptation to local market conditions appears to be beneficial; for example, sector medians improve performance in Brazil (Barros et al., 2024), and optimal return on equity thresholds differ in China (Chen, 2024). Several studies indicate that extreme market conditions, such as those during the 2020 pandemic (Wu and Begum, 2021), may weaken the predictive power of these strategies.

Despite numerous empirical studies confirming the validity of Warren Buffett's strategy in individual national markets, there is a lack of comprehensive comparative studies in the literature. There is a clear research gap in systematising knowledge about the transferability of this strategy between developed and emerging markets and identifying the behavioural and market determinants that influence its adaptability. Furthermore, current literature reviews rarely address how structural market frictions, such as liquidity constraints and information asymmetry in emerging economies, alter the predictive power of the classic "Graham-and-Dodd" metrics utilized by Buffett. The aim of this article is to conduct a systematic review of the scientific literature in order to assess the accuracy, adaptability, and key factors determining the success of strategies inspired by Buffett's philosophy in diverse global markets. Empirical evidence will be analysed from both developed markets, where the strategy was originally applied, and emerging markets, which are characterised by different dynamics and levels of effectiveness. The novelty of this study lies in its comprehensive and structured assessment of

how market frictions and behavioural factors modify the predictive power of classic Buffett-style valuation metrics in emerging economies.

The article consists of six parts. The first part provides an introduction to Buffett's strategy and highlights the need for a comprehensive literature review. The second part presents the mechanism of operation and the evolution of the value investing concept. The third part provides a review of the literature on the accuracy of Buffett's strategy in diverse international markets. The fourth part describes the methodology used in the review. The fifth part analyses the existing scientific achievements and includes a discussion. The last and sixth parts contain key conclusions and indicate future directions for research.

2. Theoretical background

Understanding the fundamental pillars of Warren Buffett's strategy is key to assessing its universality. His approach, although often simplified to the concept of "value investing", is in fact a multidimensional process that has evolved over decades. Initially rooted in Benjamin Graham's classical philosophy, it has evolved into a more complex strategy in which the search for value is inextricably linked to the assessment of a company's quality and long-term prospects.

Buffett's philosophy is based on principles inherited from his mentor, Benjamin Graham, co-author of the seminal work *Security Analysis* (Graham, Dodd, 1934). The main idea is to buy shares in companies at a price significantly lower than their intrinsic value (Frazzini, Kabiller, Pedersen, 2013). The difference between intrinsic value and market price creates a so-called margin of safety, which is a key mechanism to reduce investment risk (Dias Jorge, 2010; Srikandi, Soekarno, 2024). In this phase of Buffett's approach, as well as in many studies testing Graham's strategies, the emphasis is on quantitative indicators such as:

- Low price-to-earnings ratio (P/E): Studies often use a P/E threshold below 15 (Chang, 2011).
- Low price-to-book ratio (P/B): A popular criterion is a P/B below 1.0 (Chang, 2011).

Contemporary academic debate points to a fundamental change in the capital structure of companies, which forces a redefinition of the concept of "book value". Traditional indicators, such as price-to-book value (P/B), on which the early phase of Buffett's strategy was based, have eroded as effective tools for selecting companies. Lev and Srivastava (2022) argue that the main reason for the "failure" of traditional value investing in the second decade of the 21st century is the imperfections of accounting standards (GAAP/IFRS), which require investments in intangible assets (such as research and development, brand building, and organisational capital) to be treated as current expenses rather than capitalisable assets. This leads to a systematic understatement of the book value of innovative companies and an artificial

overstatement of their valuation ratios, which misclassifies them as expensive "glamour" companies (Ewens et al., 2024).

Empirical research indicates that taking intangible capital into account restores the predictive power of value strategies. Eisfeldt, Kim, and Papanikolaou (2022) showed that portfolios constructed on the basis of "adjusted book value" (intangible-adjusted book-to-market), which takes into account the replacement value of knowledge and organisation, generate significantly higher risk-adjusted returns than the traditional HML factor, especially in technology-intensive sectors. Park (2022) confirms these findings on an international sample, suggesting that Buffett's information advantage in recent years may have been based on his intuitive perception of the "hidden value" in intangible assets, as best illustrated by the evolution of his portfolio towards companies such as Apple, characterised by a strong brand and ecosystem, despite high traditional valuation multiples.

Over time, Buffett developed Graham's philosophy, concluding that price is only one of its elements. The criterion of quality became key, which is best summed up by his famous saying, quoted, among others, in the work of Frazzini et al. (2013): "It is better to buy a great company at a fair price than a fair company at a great price". "Quality" in Buffett's context is not an abstract concept but is based on specific, measurable attributes that the scientific literature identifies using the following indicators:

- Stable and growing profits: The company should demonstrate consistent profitability over the years.
- High return on equity (ROE): Many studies use an ROE threshold above 15% as an indicator of effective use of shareholders' capital (Srikandi, Soekarno, 2024).
- Low debt: A conservative capital structure, often measured by a debt-to-equity ratio (D/E) below 0.5, indicates financial stability (Bhakti, Widjaja, 2023).
- Sustainable competitive advantages (so-called "moats"): A company's ability to defend its profitability against competition, resulting, for example, from a strong brand, economies of scale, or patents.

Contemporary financial literature broadens the definition of "quality" in investment strategy, integrating it with ESG factors, in particular, corporate governance. Cunningham (2020) introduces the concept of "quality shareholders", a group of investors characterised by a high concentration of capital and a long-term investment horizon, of which Berkshire Hathaway is a prime example. Research indicates that the presence of such a group in a company's ownership structure is correlated with higher capital allocation efficiency and less pressure on short-term results, which is a significant competitive advantage.

Otero-González et al. (2025) provide empirical evidence that combining financial quality indicators (such as ROIC) with an assessment of the "economic moat" and ESG indicators allows for more effective company selection and avoidance of so-called "value traps". In their study, strategies that integrate management quality assessment with fundamental analysis

generated higher risk-adjusted returns, confirming Buffett's intuition that the quality of managers is as important as the quality of assets.

Research conducted by Frazzini, Kabiller and Pedersen (2013) significantly changed the academic perception of Buffett's success. The authors argue that his above-average results can be explained largely not by a "magic touch" but by systematic exposure to well-identified market risk factors. They decomposed Berkshire Hathaway's strategy, identifying four key components – see Table 1.

Table 1.
Key components of Buffett's strategy

Factor	Description
Value	Buying shares that are cheap relative to their fundamentals (e.g. high book-to-market ratio).
Quality	Buying shares in high-quality companies (profitable, stable, growing).
Low Risk (Betting Against Beta)	Buying shares with low volatility and a low beta ratio.
Leverage	Using cheap leverage, mainly through insurance reserves (known as "insurance float").

Source: Frazzini, Kabiller and Pedersen (2013).

Based on the above analysis, it can therefore be concluded that Buffett's strategy is a complex concept combining a disciplined search for undervalued companies with a rigorous assessment of their quality and long-term potential. As research shows, this seemingly intuitive process can also be interpreted as consistent exposure to factors that, in financial theory, are associated with risk premiums. This multidimensionality provides a starting point for analysing its application in different markets.

3. Methodology

The reliability of a literature review depends on the use of a transparent and systematic methodology. The purpose of this section is to describe in detail the process of selection, analysis and synthesis of scientific research that formed the basis for the conclusions formulated in this article. The approach used was designed to ensure objectivity and comprehensiveness of the analysis.

The literature search was conducted using key academic databases, including Google Scholar, Scopus, as well as university repositories and research archives. A combination of keywords was used to identify the empirical studies best suited to the topic under analysis. The literature search was conducted based on the following keywords: "Warren Buffett", "value investing", "Graham's strategy", "Piotroski's F-score", "fundamental analysis". These terms were combined with the names of specific markets or regions (e.g. "Brazil", "India", "emerging markets", "developed markets") to narrow down the results to contextual studies.

A preliminary exploration of the Scopus database using the defined keywords allowed us to identify a set of scientific publications related to modern investment methods, fundamental analysis and market strategies. An analysis of the temporal structure of these publications, based on the bibliography provided, reveals a clear upward trend in recent years. Although the fundamental principles of Warren Buffett's strategy (value investing) have been present in the literature for decades (e.g. Hirshleifer, Teoh, 2003; Damodaran, 2007), the vast majority of the empirical and technological articles analysed were published after 2018, with a clear accumulation in the years 2023–2025. This testifies to the unflagging interest in verifying classic investment paradigms in the face of modern financial engineering.

A geographical analysis of the authors' affiliations and the markets under study indicates a significant diversification of research areas. Contemporary literature goes beyond the American market (traditionally associated with Buffett), exploring emerging markets and specific local stock exchanges. The collection includes studies on Turkey (Bildik, Tokmakcioglu, 2024), Thailand (Natthakunlanan, Praditsangthong, 2024) and Malaysia (Zainudin et al., 2024; Jiet, Manual, 2019). This phenomenon suggests that fundamental indicators (such as those used by Buffett: ROE, low Beta, P/B) are being tested for universality in markets with varying degrees of efficiency and liquidity.

Based on an analysis of keywords and abstracts collected in the database, four main thematic clusters have been identified that define the current directions of research on the adaptation of fundamental strategies:

- **Integration with AI and Large Language Models (LLMs)** – the most dynamically developing area is the confrontation of traditional "buy and hold" strategies with artificial intelligence algorithms. Researchers are striving to automate the decision-making processes that Buffett performs qualitatively. Tong et al. (2025) present the "Ploutos" framework, which uses financial large language models (Financial LLM) to explain the prediction of stock market movements. In turn, Natthakunlanan and Praditsangthong (2024) have developed a machine learning-based advisory bot for the technology sector in Thailand, integrating fundamental data (such as DCF) with technical analysis. Importantly, the research by Sun et al. (2019) directly compares machine learning strategies with Warren Buffett's strategy, showing that in the long term, the "buy and hold" approach can still compete with algorithms.
- **Advanced Valuation and Selection Methods (Quantitative Value)** – the second significant trend is the refinement of valuation methods through modern statistical tools, which represents an evolution of the classic "margin of safety". Bildik and Tokmakcioglu (2024) propose an innovative approach based on Triangular Spherical Fuzzy Sets for IPO analysis, combining microeconomic indicators with long-term competitive advantage. Zainudin et al. (2024) use clustering methods (including k-Means) to automatically label defensive Sharia-compliant companies based on indicators close to Buffett's philosophy (low P/E, low Beta).

- **Corporate Governance and Ethics** – contemporary literature places strong emphasis on management quality, which corresponds to the "quality" criterion in Buffett's strategy. Tingle (2024) in his work "Hard Lessons in Corporate Governance" analyses failures in applying corporate governance to improve social and market performance. Rezaee (2025) provides a comprehensive overview of regulations and best practices in *corporate governance*, emphasising the role of managerial responsibility and sustainable development, which is a modern development of qualitative management analysis.
- **Prediction and Behavioural Aspects of the Market** – the last cluster covers research on the effectiveness of forecasting in the context of investor behaviour. Makridakis et al. (2025), analysing the results of the M6 forecasting competition, examine the gap between the accuracy of forecasts and investment decisions, undermining the efficient market hypothesis to some extent. These works, together with earlier research on "herd behaviour" (Hirshleifer, Teoh, 2003), provide a theoretical background for understanding why contrarian strategies (such as Buffett's) remain effective in the face of market anomalies and crowd cognitive errors.

The review includes peer-reviewed scientific articles, chapters in monographs, theses (master's and doctoral) and research reports published in English and Polish. The key criterion for inclusion was the presence of an empirical test of an investment strategy based on the clearly defined principles of Warren Buffett, Benjamin Graham, or related fundamental analysis methods (e.g., Piotroski's F-score) in public equity markets. The studies had to present measurable results, such as rates of return, risk-adjusted measures or statistical test results. Articles of a purely theoretical or journalistic nature, market opinions and works that did not present original empirical research were excluded from the review. Overall, the study draws on 44 scholarly articles that address the investigated topic.

After selecting the literature, a thematic analysis was conducted to systematically synthesise the data. Key information was extracted from each eligible study and then categorised. These categories included:

- Strategy components: specific criteria and indicators used for stock selection (e.g., P/E, P/B, ROE, D/E).
- Performance measures: measures used to evaluate strategy effectiveness (e.g., average returns, risk-adjusted returns, Jensen's alpha, Sharpe ratio, Treynor ratio).
- Contextual factors: characteristics of the market or research sample that may have influenced the results (e.g., company size, liquidity, study period, market efficiency).
- Main conclusions and interpretations of the authors: explanations proposed in the studies for the observed results (e.g., references to market inefficiency, risk premium, behavioural errors).

In summary, bibliometric data indicate that the value investing strategy is evolving towards Quantitative Value Investing. Contemporary research does not reject classic fundamental indicators, but seeks to optimise them using Big Data, machine learning and fuzzy logic, while extending the analysis to include a formalised framework of corporate governance and business ethics. The methodology used allowed for the systematisation of evidence from different markets and theoretical frameworks, which can form the basis for in-depth analysis and discussion of the results.

4. Results

Assessing the universality of Buffett's strategy requires analysing its relevance in diverse economic, regulatory and cultural contexts. The popularity of his investment philosophy has led to numerous empirical studies testing adaptations of the concept on stock exchanges around the world. The following review highlights key findings from the literature, broken down by developed and emerging markets, to identify patterns and differences in performance.

The US market, where Buffett's concept originated, is the most thoroughly researched area. Historical studies clearly confirm the spectacular success of his approach. Martin and Puthenpurackal (2008) showed that between 1976 and 2006, Berkshire Hathaway's public stock portfolio outperformed the S&P 500 index in 27 out of 31 years, achieving an average annual advantage of more than 11 percentage points. The author points out that achieving such results by chance is statistically extremely unlikely. In turn, Frazzini et al. (2013) explained these results in their groundbreaking work, arguing that Buffett's success was due to consistent exposure to value, quality, low-risk factors (so-called "betting against beta") and the use of cheap leverage. However, more recent data suggest that the effectiveness of the strategy may have weakened. A study analysing the synthetic "B-score" indicator, based on Buffett's ideas, showed that in 2020, during the COVID-19 pandemic, this indicator lost its predictive power in the US market, raising questions about its resilience to extreme market shocks (Wu, Begum, 2021).

Studies from other developed markets provide more mixed results. Bird and Gerlach (2003), analysing the British and Australian markets, found that fundamental data can be effectively used to improve simple value strategies. At the same time, they emphasised that key predictive indicators differ between markets and change their accuracy over time, suggesting the need for local adaptation rather than blind copying. In turn, a study of Graham's strategy based on net current asset value (NCAV/MV) on the London Stock Exchange showed that between 1981 and 2005 it generated significantly positive market-adjusted returns, even after taking into account the effect of company size, confirming the durability of some classic value investing principles (Xiao, Arnold, 2007). The validity of the macroeconomic view of value, which is

key to Buffett, is also confirmed by a study by Swinkels and Umlauf (2022). They showed that the so-called "Buffett indicator", i.e. the ratio of market capitalisation to GDP (MVE/GDP), is a strong predictor of ten-year returns in 14 developed markets. When this ratio is low, future returns are usually high, and vice versa, which supports the thesis of a long-term return of markets to the mean.

In emerging markets, which are often characterised by lower information efficiency and greater volatility, strategies based on fundamental analysis seem to find fertile ground. Table 2 presents the key findings from studies conducted in selected countries.

Table 2.

Summary of research results on value investing strategies in emerging markets

Author and year	Market	Method/criteria used	Main conclusions
Dantas Neto (2013)	Brazil	Buffett criteria (P/L, ROE, P/B, etc.) + margin of safety	The strategy significantly outperformed passive and active funds (2003-2012) with lower risk.
Galdi, Lopes (2013)	Brazil	Piotroski's F-score (as a proxy for quality/value)	The strategy generates very high returns, but this effect disappears for liquid and arbitrageable stocks. Success is driven by market friction and illiquidity.
Bhatt (2019), Tripathy, Pani (2017)	India	Graham's formula, Piotroski's F-score	Both Graham's formula (average return of 39.43%) and the F-score strategy have proven effective in generating above-average returns.
Srikandi, Soekarno (2024), Bhakti, Widjaja (2023)	Indonesia	Buffett's criteria (including D/E < 0.5, P/E < 5, ROE > 15%)	The strategy is successfully applied; an analysis of ANTM showed significantly higher returns than the index in 2013-2021, but in 2022 its result was negative and worse than the index.
Chang (2011)	Malaysia	Graham's criteria (P/E < 15, P/B < 1, etc.)	Most of Graham's selection criteria generated returns that were statistically higher than market returns in the years 2000-2009.

Source: own elaboration.

It is important to note that some of the excess returns observed in emerging markets, particularly in studies by Galdi & Lopes (2013) and Dantas Neto (2013), may be partly driven by liquidity constraints and other market frictions. Highlighting these cases clarifies that higher performance in certain markets can reflect compensation for illiquidity rather than purely superior identification of mispriced assets.

This divergence in results – high returns in emerging markets on the one hand and high volatility in developed markets over time on the other – raises fundamental methodological questions: is the observed 'alpha' a true result of information advantage, a premium for low liquidity and other market frictions, or a consequence of the models used in the research?

The dynamic development of artificial intelligence (AI) in asset management has also raised questions about the sustainability of the information advantage of traditional value investors. Anuar, Sulaiman and Mohamad (2025) in a comparative study covering the years 2022-2024 showed an interesting dichotomy: AI-driven funds showed an advantage in bear markets (downside protection) thanks to rigorous risk management algorithms, but it was "human" managers using a fundamental approach who achieved higher returns during market upturns.

These results suggest that qualitative business assessment, which is at the core of Buffett's philosophy, allows for more effective exploitation of long-term growth trends that may be prematurely liquidated by conservative AI algorithms.

Dhar and Sedoc (2025) point out that current AI models, despite their sophistication in numerical data processing, still encounter difficulties in replicating "contextual reasoning" – the ability to synthesise financial data with an assessment of management quality and competitive strategy. In this light, Buffett's strategy, based on a deep understanding of the nature of business and patience ("buy and hold"), appears not as a relic of the past, but as a complementary approach that exploits behavioural inefficiencies that algorithmic models are unable to fully eliminate.

5. Discussion

After presenting the results of empirical research from various markets and bibliometric analysis, the next subsection provides a synthesis and critical assessment of these results. The aim of this part of the article is not only to summarise, but also to identify recurring patterns, potential contradictions and deeper implications arising from the literature review. The analysis focuses on four key thematic areas that have emerged in the literature: (1) the universality of the strategy in a broad market context, (2) the assessment of the role of quality within the concept of value investing, (3) the determinants of the strategy's success, (4) the cyclical nature of the value premium in the context of the "value winter" and the issue of market concentration.

One of the central questions is whether the basic principles of Buffett's strategy are universal. A review of the literature suggests that the answer is complex. Indicators such as low price-to-book (P/B) ratios and high return on equity (ROE) show consistent predictive power in many emerging markets, such as Indonesia, Malaysia and Brazil. However, in more mature and competitive markets, such as the US, their effectiveness tends to be variable and period-dependent. Market efficiency and arbitrage limits play a key role in this convergence. A study by Galdí and Lopes (2013) on the Brazilian market provides key insights here. The authors showed that above-average returns from a strategy based on Piotroski's F-score (a proxy for quality and value) are concentrated in the low-liquidity segment and disappear for companies where arbitrage is easy to carry out. This suggests that the observed "alpha" in emerging markets may not be solely the result of mispricing, but largely a premium for illiquidity and the risk associated with market friction. In Brazil, the observed "alpha" therefore appears to be largely compensation for structural market friction rather than a pure reward for identifying mispricing in the classical sense.

The evolution of Buffett's strategy from pure Grahamian value towards quality is well reflected in the academic literature. The addition of "quality" criteria such as low debt, earnings stability and high profitability significantly improves the performance of traditional value strategies. Piotroski's F-score (2000) is the best example of this – it is a simple, accounting-based tool that effectively separates "winners" (companies with improving fundamentals) from "losers" (companies in further crisis) in a portfolio of stocks with a high B/M ratio. Its effectiveness has been confirmed both in the US market and in India (Tripathy, Pani, 2017). However, as shown by Bird and Gerlach (2003), there is no single, universal set of quality indicators. The optimal combination of these measures may be unstable over time and vary depending on the specifics of a given country and its regulatory environment. This reinforces the conclusion that while the principle of seeking quality is universal, its practical implementation requires a deep understanding of the local context.

The academic literature offers two main, though not necessarily mutually exclusive, explanations for the success of the value/quality strategy: behavioural and risk-based.

According to the first approach, the strategy exploits systematic cognitive errors made by investors. Lakonishok, Shleifer and Vishny (1994) argued that investors tend to overreact to negative news and extrapolate poor performance into the future, leading to an excessive discounting of "loser" stocks. At the same time, they neglect boring but stable value companies. Buffett's strategy in this view is a form of rational contrarianism that profits from these irrational behaviours.

More recent research, in particular the work of Frazzini, Kabiller and Pedersen (2013), interprets the phenomenon of Buffett's strategy differently. They argue that above-average returns are not a "free lunch" but a reward for taking on a certain type of systematic risk. Low-volatility (low beta) value and quality stocks may be less desirable during bull markets, and their performance may be correlated with specific economic conditions. In this view, Buffett's success lies in intelligently and disciplinedly constructing a portfolio that consistently captures these risk premiums, further amplifying them with cheap leverage.

Moreover, the two explanations above are not necessarily mutually exclusive. It is possible that systematic risk factors such as "value" are in fact a quantitative reflection of behavioural biases among investors, such as excessive pessimism towards companies with poor past performance. In this view, Buffett's strategy does not so much choose between risk and cognitive error, but rather exploits risk that is systematically underestimated because of these cognitive errors.

Assessing the accuracy of Buffett's strategy requires an analysis of the period of structural underweighting of value companies, referred to in the literature as the "Value Winter", which lasted from the 2008 financial crisis until 2020. Ang (2023) documents that during this period, the value factor experienced an unprecedented decline in effectiveness, which is associated with a global environment of very low interest rates, favouring growth companies with "long duration" cash flows.

However, research covering the period after 2021 points to a change in the market regime. Weng and Butler (2022) argue that the return of elevated inflation and the normalisation of monetary policy have restored the negative correlation between interest rates and technology company valuations, which has relatively strengthened value portfolios. Historical data suggest that in periods of inflation exceeding 3-4%, the value premium expands significantly (Swedroe, 2021). Furthermore, Asness (2024) points out that the "value spread" – the difference in valuation between the cheapest and most expensive deciles of the market – reached extreme levels in 2022-2024, comparable only to the dot-com bubble of the 2000s, which historically has been a strong predictor of future above-average returns for fundamental strategies based on mean reversion.

The unprecedented concentration of returns in a narrow group of technology companies (the so-called "Magnificent 7") in 2023-2024 posed a challenge to traditionally diversified value strategies. Grobys (2025) points out in his analysis of systemic risk that the valuations of these entities showed characteristics of speculative bubbles (according to LPPLS models), which in theory should have prompted value investors to avoid them. Paradoxically, the relative success of the Berkshire Hathaway portfolio during this period was not due to avoiding the technology sector, but to a selective, high concentration in Apple stocks.

This demonstrates the flexibility of Buffett's strategy, which, unlike the rigid algorithms of value indices (which reject companies with high P/E ratios), allows investments in growth companies as long as they have a dominant market position and generate high free cash flows (Wang, 2025). This attitude of "concentrated eclecticism" mitigates the risk of underweighting key sectors of the economy, which is a common cause of underperformance by traditional value funds during periods of technological bull markets.

6. Conclusions

A systematic review of the scientific literature allows us to draw multidimensional conclusions about the relevance of Warren Buffett's investment strategy in various global markets. Analysis of empirical evidence from developed and emerging markets sheds light on the universal principles underlying his philosophy, as well as the key contextual factors that moderate its effectiveness.

The direct answer to the question of the relevance of Buffett's strategy in different markets is that the fundamental principles of the strategy, combining a disciplined search for value with rigorous quality assessment, show significant relevance in many global markets. Evidence from countries as diverse as Brazil, Indonesia and India shows that portfolios constructed based on these principles consistently generate above-average and often impressive rates of return.

At the same time, it is important to emphasise a key caveat: the effectiveness and optimal implementation of the strategy are strongly dependent on the local context. In emerging markets, which are characterised by lower information efficiency, lower liquidity and limited arbitrage opportunities, the strategy may generate higher returns. However, as some studies suggest, part of this excess may be compensation for taking on additional risk (e.g. liquidity risk) and not solely the result of identifying mispriced assets. In turn, in highly developed and competitive markets, such as the US, the accuracy of the strategy may decline during periods when value and quality factors underperform and information advantages are much more difficult to obtain.

The implications for investors are therefore more profound than simply adapting indicators. Buffett's philosophy should be treated not as a ready-made algorithm, but as a method of heuristic search for market-specific characteristics of "quality" and "value". An investor in an emerging market may find that the "quality" premium is more strongly linked to cash flow stability in an unstable political environment, while in a developed market it may be linked to the strength of intellectual property and barriers to entry. From a theoretical perspective, Buffett's philosophy provides a robust framework for understanding the interplay between value, quality, and market structure, showing how behavioural tendencies and systematic risks shape asset pricing. Practically, these insights guide investors in tailoring fundamental analysis to local conditions, taking into account the contextual constraints of universal models, and remaining flexible amid evolving market dynamics.

It is also important to acknowledge the limitations of the reviewed studies. Reliance on historical data, differences in methodology, and potential market biases make direct comparisons challenging. Nevertheless, the literature provides valuable insights: integrating value and quality metrics consistently enhances performance, the influence of local market characteristics is significant, and qualitative business assessment remains a crucial complement to quantitative approaches, particularly in volatile or less efficient markets.

Future research should focus on more targeted questions arising from the literature reviewed, such as

- Does the "alpha" generated by value strategies in emerging markets, identified by Galdí and Lopes (2013), among others, decline over time as the liquidity and efficiency of these markets increase?
- How does the changing structure of markets (e.g., the growing share of passive investors) affect the sustainability of the premiums for "quality" and "low risk" factors, which were the basis of Buffett's success according to Frazzini et al. (2013)?

In summary, Warren Buffett's legacy is not so much a rigid set of rules as a powerful analytical framework for making rational investment decisions. A review of the literature confirms that although the world is changing and markets are evolving, the enduring value of principles based on a deep understanding of business, patience and discipline in assessing value and quality remains unchanged.

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THE EFFECTIVENESS OF THE PIOTROSKI F-SCORE STRATEGY ACROSS INTERNATIONAL MARKETS: A LITERATURE REVIEW

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Purpose: This article conducts a comprehensive and critical review of the empirical literature on the Piotroski F-score strategy, assessing its effectiveness, international robustness, theoretical underpinnings, practical limitations, and evolutionary adaptations in global equity markets.

Design/methodology/approach: The study employs a targeted literature review methodology. Peer-reviewed publications were systematically identified through searches in Scopus and Web of Science databases using keywords such as "Piotroski F-score", "F-score", "fundamental analysis", and "value investing". Rigorous inclusion criteria focused on empirical studies testing the strategy or its modifications across defined markets and periods, excluding purely theoretical or non-academic works. Findings were synthesized by geographic context, performance outcomes, sources of returns, and thematic clusters identified via bibliometric analysis.

Findings: The Piotroski F-score exhibits strong cross-market effectiveness, particularly in emerging economies with lower informational efficiency, where it generates significant risk-adjusted premiums (e.g., Walkshäusl, 2020). The return premium is predominantly attributed to behavioral mispricing from investor underreaction rather than risk compensation. The strategy performs best among small-cap, low-liquidity stocks and serves as a valuable complement to multifactor approaches. Notable exceptions (e.g., Poland) and practical frictions (transaction costs, capacity constraints) highlight contextual dependencies. Contemporary research extends the F-score through machine learning, ESG integration, distress prediction, and macroeconomic conditioning.

Research limitations/implications: The review is constrained to published empirical studies and lacks a formal meta-analysis. Future research should explore machine learning enhancements, macroeconomic sensitivities, transaction cost impacts on net returns, and behavioral mechanisms of information diffusion to further refine theoretical foundations.

Practical implications: The F-score remains a low-cost, accessible tool for fundamental investors, especially as an overlay in value or multifactor strategies. However, practitioners—particularly large institutions—must account for liquidity constraints and implementation costs, which can substantially erode gross returns in real-world applications.

Originality/value: This review offers the first structured international synthesis of Piotroski F-score literature, documenting its evolution to a versatile framework while evaluating universality, drivers, and viability across global markets.

Keywords: Piotroski F-Score, value investing, fundamental analysis, financial strength, stock returns.

Category of the paper: Literature review.

1. Introduction

A central debate in modern finance theory pits proponents of the Efficient Market Hypothesis (EMH; Fama, 1970), which posits that asset prices fully reflect all available information, against evidence of market anomalies documented in the literature. One prominent example is the post-earnings-announcement drift (Bernard, Thomas, 1989), where stock prices exhibit systematic continuation in the direction of earnings surprises, indicating that markets do not always incorporate new information instantaneously or rationally. Such inefficiencies provide the foundation for fundamental analysis-based investment strategies aimed at exploiting discrepancies between market prices and firms' intrinsic value (Abarbanell, Bushee, 1998).

These strategies are rooted in value investing, a approach pioneered by Graham and Dodd (1934). The core premise is that systematically selecting stocks with low valuation multiples—such as the book-to-market ratio (B/M) - generates superior long-term returns. A critical challenge, however, is the "value trap" phenomenon: many seemingly undervalued firms are inexpensive for fundamental reasons, as deteriorating financial health ultimately results in poor performance and investor losses.

To address this challenge, Piotroski (2000) introduced the F-score, a straightforward yet effective fundamental scoring system. The F-score aggregates nine binary accounting-based signals derived from publicly available financial statements to measure a firm's financial strength. By applying this high F-score filter to a portfolio of high book-to-market stocks, the strategy identifies likely "winners" with improving fundamentals while avoiding "losers" characterized by deteriorating financial condition, thereby significantly reducing exposure to value traps.

Empirical evidence on the Piotroski F-score strategy reveals considerable variation in performance across market contexts and firm characteristics (e.g., Bülow, 2017; Krauss et al., 2015; Singh, Kaur, 2015; Pilch, 2023; Walkshäusl, 2020; Ho et al., 2023; Lopes, Galdi, 2006). Studies on the U.S. market generally confirm that high book-to-market stocks with high F-scores outperform those with low scores, though reported returns differ substantially depending on sample periods, portfolio construction, and rebalancing frequency. For instance, certain implementations involving frequent rebalancing have documented elevated returns for long-only strategies. In markets such as India and Poland, high F-score value stocks have similarly generated superior performance, including statistically significant risk-adjusted returns or positive annual excess returns relative to low-score portfolios (Singh, Kaur, 2015; Pilch, 2023). The strategy's effectiveness appears particularly pronounced in emerging markets with lower informational efficiency (Ho et al., 2023; Lopes, Galdi, 2006). One notable example from Vietnam shows high F-score portfolios delivering substantial positive raw and risk-adjusted returns with strong statistical significance. Cross-country evidence further supports the

robustness of the F-score strategy, with a comprehensive study documenting annual risk-adjusted premiums for high-minus-low F-score portfolios of approximately 9.9% in developed (non-U.S.) markets and 12.0% in emerging markets (Walkshäusl, 2020). In contrast, evidence from the U.S. indicates that the strategy's efficacy may vary over time, with some analyses suggesting diminished or conditional performance in more recent periods after controlling for additional risk factors (Turtle, Wang, 2017). Across the reviewed studies, the strongest returns are typically observed among small- and medium-sized firms or stocks with lower liquidity, where mispricing opportunities are greater. However, several studies emphasize significant practical implementation challenges, including liquidity constraints, elevated transaction costs, and limited strategy capacity, which can substantially erode net returns in real-world settings (e.g., Bülow, 2017; Krauss et al., 2015; Hyde, 2018; Pilch, 2023; Lopes, Galdi, 2006).

In the realm of academic research, previous studies have predominantly centered on individual markets. These markets range from highly developed stock exchanges in nations such as the United States or Germany to emerging markets in countries like Vietnam or India. The utilization of diverse methodologies and research periods across these studies leads to challenges in synthesizing the findings and drawing universal conclusions about the strategy's applicability. This article addresses a significant research deficiency by presenting the inaugural comprehensive, international synthesis of the extant literature concerning the efficacy of the Piotroski F-score strategy. The study's originality is manifested in three pivotal aspects.

- Firstly, the study aggregates quantitative rates of return from both developed and emerging markets in order to identify structural factors that determine the effectiveness of the strategy in question. Factors considered include information asymmetry and market efficiency.
- Secondly, in contrast to conventional reviews, the article undertakes a critical analysis of the issue of “institutional scalability.” It does so by confronting theoretical backtest results with the realities of transaction costs and liquidity constraints, which frequently receive insufficient attention in academic literature.
- Thirdly, the paper charts the evolution of the F-Score methodology towards contemporary applications, encompassing integration with machine learning and ESG (Environmental, Social, Governance) criteria.

This article provides a comprehensive and critical review of the empirical literature on the Piotroski F-score strategy, evaluating its effectiveness, cross-market robustness, and practical limitations. By synthesizing evidence from a wide array of international settings—ranging from highly efficient U.S. and European markets to less efficient emerging markets—the review identifies the contextual factors that enhance the strategy's performance as well as those that constrain its applicability and profitability.

The article is structured as follows. Section 1 introduces the Piotroski F-score and its role in fundamental analysis. Section 2 details the construction and mechanics of the F-score investment strategy. Section 3 provides a comprehensive review of the empirical literature

evaluating the strategy's effectiveness across diverse international markets. Section 4 outlines the methodology employed in conducting this literature review. Section 5 synthesizes the findings, offers a critical analysis, and discusses key implications. Finally, Section 6 presents the main conclusions and suggests avenues for future research.

2. The Piotroski F-Score Strategy

A thorough understanding of the Piotroski F-score construction is essential for accurately interpreting the empirical evidence on its performance. The enduring appeal of Piotroski's (2000) approach stems from its simplicity and exclusive reliance on publicly available financial statement data, requiring no proprietary information or sophisticated analytical tools. This accessibility renders the F-score a versatile and practical screening mechanism, readily applicable by a broad spectrum of investors across diverse international markets.

The Piotroski F-score is calculated as the aggregate of nine binary (0/1) signals, organized into three broad categories: profitability, financial leverage/liquidity (often referred to as financial stability), and operating efficiency. A firm receives one point for each signal it satisfies and zero otherwise, resulting in a composite score ranging from 0 to 9. The individual signals comprising the F-score are detailed in Table 1.

Table 1.
Piotroski F-Score Signals

Category	Signal	Description	Criterion for Scoring 1 Point
Profitability	ROA	Return on assets	ROA > 0 in the current fiscal year
	CFO	Operating cash flow	CFO > 0 in the current fiscal year
	Δ ROA	Change in return on assets	Δ ROA > 0 (improvement relative to prior year)
	ACCRUAL	Earnings quality	CFO > Net income
Leverage, Liquidity, and Funding	Δ LEVER	Change in financial leverage	Decrease in long-term debt-to-average total assets (or no increase)
	Δ LIQUID	Change in current ratio	Increase in current ratio relative to prior year
	EQ_OFFER	Equity issuance	No new equity issuance in the current fiscal year
Operating Efficiency	Δ MARGIN	Change in gross margin	Increase in gross margin relative to prior year
	Δ TURN	Change in asset turnover	Increase in asset turnover relative to prior year

Source: Author's elaboration based on Piotroski, 2000.

The resulting F-score ranges from 0 (indicating the weakest financial condition) to 9 (indicating the strongest). Following Piotroski (2000), firms with high F-scores—typically those scoring 8 or 9—are classified as financially strong and expected to exhibit improving fundamentals. In subsequent international studies, researchers have frequently adopted a more inclusive threshold of 7-9 to construct larger and better-diversified portfolios, particularly in markets with fewer listed firms (e.g., Pătări et al., 2018, 2022). Conversely, low F-score firms—generally those scoring 0-2 (or sometimes 0-1)—are identified as financially weak and prone to further deterioration.

Piotroski's (2000) original investment strategy employs a zero-investment long-short portfolio constructed as follows. First, the universe of stocks is restricted to those in the highest book-to-market (B/M) quintile, identifying a sample of value firms. Within this subset, stocks are ranked by F-score: long positions are taken in high F-score firms (typically scoring 8-9), while short positions are established in low F-score firms (typically scoring 0-1). The portfolio is rebalanced annually at the end of each fiscal year. Although initially applied in this specific context, subsequent research has established that the F-score's predictive ability extends well beyond traditional value stocks. However, as the ensuing literature review will illustrate, its effectiveness is not unconditional and varies systematically with market conditions and implementation details.

3. Literature review

Since its introduction in Piotroski (2000), the F-score has spurred a substantial body of empirical research examining its effectiveness across diverse market environments. This literature review synthesizes key findings from these studies, evaluating the strategy's robustness and universality by analyzing performance evidence from markets differing in institutional development, informational efficiency, and liquidity.

The foundation for subsequent research is Piotroski's (2000) seminal study, which examines the U.S. market over the period 1976-1996. Focusing on the quintile of firms with the highest book-to-market (B/M) ratios—corresponding to the 20% of stocks with the lowest price-to-book values—Piotroski sorts these value stocks into portfolios based on their F-score. The zero-investment hedge strategy that buys high F-score firms (scores of 8-9) and shorts low F-score firms (scores of 0-1) generates an average annual market-adjusted return of 23 percentage points. In absolute terms, the high F-score portfolio earns 23.5% per year, substantially outperforming both the broad CRSP value-weighted market index (which returns 17.9%) and the average value stock. This evidence demonstrates that the F-score effectively discriminates between strong and weak value firms, delivering significant excess returns in the U.S. context (Piotroski, 2000).

Subsequent empirical research on the Piotroski F-score strategy in the U.S. market has primarily explored three interrelated themes: the economic sources of the observed return premium, practical implementation constraints, and the impact of macroeconomic conditions.

Regarding the sources of the F-score return premium in the U.S. market, Piotroski and So (2012) provide both conceptual and empirical evidence that it stems primarily from investor expectation errors regarding firms' fundamental trajectories, leading to systematic mispricing rather than compensation for systematic risk. The F-score effectively identifies financially robust value firms whose improving prospects are underappreciated by the market, thereby

explaining portions of the value and momentum anomalies. From a practical perspective, Krauss et al. (2015) revisit the strategy over the 2005-2015 period using realistic implementation assumptions. Their analysis reveals that gross returns diminish substantially—and in many cases turn negative—after accounting for transaction costs, bid-ask spreads, and liquidity constraints, particularly in frequent rebalancing scenarios or among small-cap and low-liquidity stocks where the theoretical premium is most pronounced. Furthermore, Anderson et al. (2021) examine the sensitivity of the F-score to macroeconomic conditions using U.S. data from 1973-2016. They document that macroeconomic variables and monetary policy exert a significantly stronger influence on firms' financial signals (and thus F-scores) during recessions than expansions, implying that financial strength becomes more contingent on external economic factors in downturns.

Evidence from developed markets outside the United States generally supports the effectiveness of the Piotroski F-score strategy, albeit with notable cross-country and contextual variation. In Germany, Pätäri et al. (2018, 2022) document substantial value added when the F-score is used to complement traditional value strategies, emphasizing its downside protection during bear markets and persistent performance over multi-year holding periods. In the United Kingdom, Rathjens and Schellhove (2011) report the counterintuitive finding that the F-score generates stronger returns among growth stocks than value stocks, while more recent work by Kupiainen (2024)—covering 2000-2022—demonstrates that integrating the F-score with price momentum materially enhances risk-adjusted performance, as evidenced by higher Sharpe ratios. On the Australian market, Hyde (2018) confirms significant abnormal returns (0.85% monthly premium for large companies and 1.36% monthly premium for small companies, in the case of capitalization-weighted portfolios), though these are largely attributable to exposure to conventional risk factors (size, value, and momentum). In the eurozone, Gimeno et al. (2020) highlight limitations of the original binary F-score construction, showing that machine-learning extensions, such as neural network-based NF-scores, deliver superior predictive power and portfolio outcomes. Across the Nordic countries (Sweden, Denmark, Finland, and Norway), Brindelid and Nilsson (2021) find that high F-score portfolios consistently outperform broad market indices over the 2012-2020 period, with the strongest results observed in Norway.

Walkshäusl (2020) provides robust cross-country evidence supporting the international applicability of the Piotroski F-score strategy. In a comprehensive analysis spanning 35 markets—including 23 developed and 12 emerging economies—the study documents significant risk-adjusted premiums for high-minus-low F-score portfolios, with particularly strong performance in emerging markets, where informational inefficiencies are more pronounced. In established markets (excluding the US), the strategy yielded an average premium of 10 per cent, whereas in emerging markets, it resulted in a premium of approximately 12 per cent. These findings are corroborated by a growing body of country-specific research in emerging economies:

- Brazil (Lopes, Galdi, 2006): The strategy proves effective, though returns are maximized over a two-year holding period, consistent with slower information diffusion in less efficient markets.
- China (A-shares; Deng, 2016): A substantial monthly premium of approximately 1.3% for long-short portfolios (approximately 16.5% per annum.), driven primarily by stocks with low liquidity, limited analyst coverage, and—counterintuitively—lower book-to-market ratios.
- India (Tripathy, Pani, 2017): High F-scores are associated with statistically significant improvements in both contemporaneous and future market-to-book ratios (MTB) and return on equity (ROE).
- Indonesia (Sharia-compliant firms; Asmadi et al., 2021): The F-score successfully identifies companies exhibiting superior financial strength.
- Turkey (Gülcan, Sakinç, 2025): High F-scores exert a positive and statistically significant influence on price-to-book, price-to-earnings ratios, and subsequent stock returns.
- Vietnam (Ho et al., 2023): The strategy generates profitable outcomes not only among value stocks but also within the growth segment, the investment yielded a return of 30.8% (raw return) and 30.5% (market-adjusted return).
- South Africa (van der Merwe et al., 2016): Buy-and-hold portfolios of high F-score firms deliver higher annual returns over one-year horizons compared with longer periods, suggesting relatively rapid incorporation of fundamental information following financial statement releases.

A notable exception to this generally positive pattern is observed in the Polish market. Pilch (2022, 2023) documents that, over the 2012-2022 period, high F-score firms underperformed the average value stock portfolio, rendering the F-score a counterproductive selection tool in this context. A quantitative analysis of the extant literature reveals the results of studies by authors such as Piotroski (2000), Walkshäusl (2020), Ho et al. (2023), and Deng (2016). Hyde (2018) and Pilch (2022, 2023) posit a robust correlation between the magnitude of excess returns generated and the degree of market development as well as its informational efficiency. The available data appear to substantiate the hypothesis of a discernible efficiency gradient. In less efficient markets (for example, Vietnam and China), simple fundamental analysis based on historical data allows for high rates of return, thus contradicting the poor form of market efficiency. In developed markets (e.g., Australia and Western Europe), the F-score premium is subject to compression, functioning primarily as a compensation for exposure to known risk factors such as size, value, and momentum, rather than as a consequence of mispricing. The case of Poland (Pilch 2022, 2023) signifies the presence of distinct local conditions (e.g. ownership structure, liquidity) that have the potential to nullify the efficacy of the strategy. Table 2 provides a comprehensive summary of empirical findings on the Piotroski F-score strategy across international markets.

Table 2.*Summary of Key Empirical Studies on the Piotroski F-Score Strategy*

Author(s) and Year	Market	Study Period	Key Findings
Piotroski (2000)	United States	1976-1996	The long-short strategy (high F-score long, low F-score short) among high book-to-market stocks generates substantial abnormal returns, with the hedge portfolio earning approximately 23 percentage points annually.
Piotroski, So (2012)	United States	Conceptual and empirical analysis	The F-score premium is attributable to behavioral mispricing stemming from investor underreaction to fundamental improvements rather than compensation for systematic risk.
Krauss et al. (2015)	United States	2005-2015	After incorporating realistic transaction costs, bid-ask spreads, and liquidity constraints, gross returns are significantly eroded, often rendering the strategy unprofitable in practice, particularly with frequent rebalancing.
Anderson, Chowdhury, Uddin (2021)	United States	1973-2016	Macroeconomic variables and monetary policy exert a stronger influence on F-scores and firm financial signals during recessions than expansions, highlighting the contingent nature of financial strength in adverse economic conditions.
Rathjens, Schellhove (2011)	United Kingdom	1991-2008	Counterintuitively, the F-score generates stronger returns among growth stocks (low B/M) than traditional value stocks.
Kupiainen (2024)	United Kingdom	2000-2022	Integrating the F-score with price momentum in a hybrid strategy significantly enhances risk-adjusted performance (higher Sharpe ratios) relative to standalone value or momentum approaches.
Hyde (2018)	Australia	1992-2013	The F-score strategy generates significant abnormal returns, but these are largely attributable to exposure to conventional risk factors (size, value, and momentum).
Pätäri et al. (2018, 2022)	Germany	2000-2015	The F-score adds substantial value as a complementary filter to traditional value strategies, offering particular downside protection during bear markets and remaining effective over three-year holding periods.
Brindelid, Nilsson (2021)	Nordic countries (Sweden, Denmark, Finland, Norway)	2012-2020	High F-score portfolios consistently outperform broad market indices across all four countries, with the strongest results observed in Norway.
Gimeno et al. (2020)	Eurozone	2006-2017	The original binary F-score has limited efficacy; a neural network-based extension (NF-score) significantly enhances predictive power and portfolio performance.
Walkshäusl (2020)	35 markets (23 developed ex-U.S., 12 emerging)	2000-2018	The F-score is a robust positive predictor of risk-adjusted returns internationally, with particularly strong premiums in emerging markets.
Deng (2016)	China (A-shares)	2006-2014	The strategy delivers substantial monthly premiums (approximately 1.3% for long-short portfolios), concentrated in low-liquidity stocks with limited analyst coverage and, counterintuitively, among lower book-to-market firms.
Tripathy, Pani (2017)	India	2010-2015	High F-scores are positively and statistically significantly associated with both current and future market-to-book ratios (MTB) and return on equity (ROE), confirming the indicator's predictive ability for future performance.
Lopes, Galdi (2006)	Brazil	1994-2004	The F-score strategy is effective, but returns are maximized over a two-year holding period, consistent with slower information diffusion in emerging markets.

Cont. table 2.

Ho et al. (2023)	Vietnam	2009-2019	The strategy generates positive returns for both value and growth stocks, demonstrating broader applicability beyond traditional high book-to-market firms.
Gülcan, Sakinç (2025)	Turkey (industrial firms on Borsa Istanbul)	2010-2022	The F-score exerts a positive and statistically significant influence on price-to-book ratios, price-to-earnings ratios, and stock returns, confirming its analytical value in this market.
Asmadi, Izzaty, Erwan (2021)	Indonesia (Sharia-compliant firms on Jakarta Islamic Index)	2017-2018	The F-score effectively discriminates financial quality among Sharia stocks, identifying 4 firms with excellent condition (F-score 8-9), 25 with moderate, and 1 with poor condition out of 30 analyzed.
Pilch (2022, 2023)	Poland	2012-2022	High F-score firms underperform the average value portfolio, representing a notable exception where the strategy fails to add value.
van der Merwe, Taft, Akinboade (2016)	South Africa (JSE)	2000-2011	One-year buy-and-hold portfolios of high F-score firms outperform five-year portfolios, suggesting relatively rapid price adjustment following positive financial disclosures.

Source: Author's elaboration.

This heterogeneous body of evidence—while predominantly supportive of the Piotroski F-score strategy's effectiveness—exhibits considerable cross-market variation that warrants systematic analysis. Such an evaluation, encompassing both theoretical explanations and practical implications, is provided in the subsequent sections of this article.

4. Methods

This article adopts the format of a targeted literature review. The objective of this approach is to provide a synthetic and critical assessment of key empirical studies on the Piotroski F-score strategy, without undertaking a formal statistical meta-analysis, while adhering to rigorous criteria in the selection and evaluation of sources.

The search strategy employed reputable international databases, primarily Scopus and Web of Science, which index peer-reviewed journals in finance, accounting, and related fields. Relevant studies were identified using targeted keywords, including "Piotroski F-score", "F-score", "Piotroski", in combination with terms such as "value investing", "fundamental analysis", "financial strength", "book-to-market", and "market anomalies". Boolean operators and truncation were applied where appropriate to capture variations and ensure comprehensive coverage.

Rigorous inclusion and exclusion criteria were applied to ensure the quality and relevance of the reviewed studies. Publications were selected for analysis if they met the following conditions: (1) conducted empirical tests of the effectiveness of the Piotroski F-score strategy or its modifications; (2) appeared in peer-reviewed academic journals or as doctoral/master's theses from reputable institutions; and (3) specified clearly defined sample periods and market

contexts. Purely theoretical papers, non-academic publications, and studies lacking methodological rigor were excluded.

An initial search of the Scopus database using the specified keywords yielded 91 peer-reviewed publications directly addressing the Piotroski F-score strategy. A bibliometric analysis of the publication timeline reveals a marked upward trend in research interest in recent years. Although Piotroski's seminal 2000 paper laid the foundation, the majority of identified studies were published after 2015, with a pronounced surge in output between 2020 and 2025. This pattern reflects a renewed scholarly focus on classical fundamental analysis-based approaches and ongoing efforts to adapt the F-score to increasingly sophisticated and dynamic market environments.

A geographical analysis of author affiliations and examined markets reveals a marked shift in research emphasis. Whereas early studies predominantly focused on the U.S. market, contemporary contributions increasingly target emerging economies, particularly in Asia. Within the reviewed sample, investigations of India (e.g., Balasubramanian et al., 2019; Kolte et al., 2022), China (e.g., Jiang et al., 2020; Chen, Chu, 2024), Vietnam (Ho et al., 2023), and Malaysia (Hiau Abdullah et al., 2019) are especially prominent. This pattern suggests that straightforward financial heuristics, such as the Piotroski F-score, may prove particularly valuable in markets characterized by lower informational efficiency and greater information asymmetry.

A keyword and abstract analysis of the assembled publications identifies four primary thematic clusters that delineate the predominant directions in contemporary research on the Piotroski F-score strategy:

- **Integration with Modern Technologies (Artificial Intelligence and Machine Learning):** The most rapidly evolving research stream involves fusing traditional fundamental analysis with advanced computational techniques. Increasingly, scholars are departing from the original binary structure of the Piotroski F-score in favor of hybrid and enhanced models. For instance, Gimeno et al. (2020) introduce a neural network-based variant (Neural F-Score) that outperforms the classic version in the eurozone context. Almeida and Neves (2022) employ evolutionary algorithms to optimize F-score-weighted portfolios, while Chen and Chu (2024) augment financial signals with sentiment analysis derived from text mining of auditors' reports. Similarly, Wu et al. (2025) integrate the F-score with big data analytics in the real estate sector, demonstrating improved predictive accuracy.
- **The Piotroski F-Score in the Context of Sustainable Development (Environmental, Social, and Governance – ESG):** A second prominent research stream explores the interplay between firms' fundamental financial strength—as captured by the F-score—and their environmental, social, and governance (ESG) performance. Emerging studies suggest a positive association, indicating that financially robust companies tend to exhibit greater transparency in ESG reporting and higher overall ESG ratings.

This correlation implies that firms with superior financial quality may possess the resources and incentives to invest in sustainable practices, potentially reflecting aligned long-term stakeholder interests.

- **Financial Distress and Bankruptcy Risk Prediction:** A third key research direction extends the application of the Piotroski F-score beyond investment portfolio selection, positioning it as an early warning indicator for corporate financial distress and bankruptcy risk. Low F-scores, signaling deteriorating fundamentals, have proven effective in identifying firms vulnerable to default. This approach is frequently compared or combined with classic models such as Altman's Z-score. For example, Rahman et al. (2021) demonstrate the F-score model's predictive power for financial distress among U.S. firms, while Kolte et al. (2018) apply both F-score and Z-score analyses to the bankruptcy of Kingfisher Airlines, confirming their utility in diagnosing severe financial deterioration across manufacturing and service sectors.
- **Sectoral and Macroeconomic Specificity:** The fourth and final thematic cluster examines the performance of the Piotroski F-score strategy under varying industry-specific and macroeconomic conditions. Research in this area reveals substantial heterogeneity in effectiveness, driven by cyclical factors and sector characteristics. For example, Anderson et al. (2025) highlight the strategy's sensitivity to business cycle phases and monetary policy regimes, with predictive power strengthening during economic downturns when fundamental signals become more salient. Sector-focused studies further illustrate this context-dependence: Sen and Neogi (2025) analyze the Indian cement industry, showing how capital-intensive cycles and regulatory pressures influence the F-score's discriminatory ability, whereas Festa et al. (2021) demonstrate its adapted utility in the pharmaceutical sector, where intangible assets and innovation pipelines interact with traditional accounting signals. Collectively, these investigations emphasize the need to calibrate the F-score approach to industry idiosyncrasies and prevailing economic environments for optimal application.

In summary, the bibliometric evidence underscores the evolution of the Piotroski F-score from a straightforward tool designed to enhance value investing strategies into a versatile, multidimensional analytical framework. Contemporary scholarship not only affirms its robustness across diverse geographic markets—particularly in emerging economies—but also extends its application through integration with artificial intelligence and machine learning techniques, as well as incorporation of non-financial factors such as environmental, social, and governance (ESG) considerations.

The adopted analytical framework facilitates a systematic synthesis of the extant literature on the Piotroski F-score strategy. Studies were categorized along three primary dimensions: geographic market context, principal findings regarding the strategy's effectiveness, and—most crucially—the identified sources of the observed return premium. This structured approach

enables a coherent discussion of the evidence and supports the derivation of robust, evidence-based conclusions.

5. Results and discussion

The empirical evidence portrays the Piotroski F-score as a highly predictive instrument whose effectiveness is significantly moderated by market-specific and structural factors. Based on the literature review, three primary areas emerge as critical for deeper analysis: (1) the strategy's universality and geographic limitations, including its varying performance across developed and emerging markets; (2) the underlying sources of the observed return premium, encompassing behavioral mispricing, informational inefficiencies, and risk-based explanations; and (3) the ongoing evolution of the strategy and its practical applications, particularly through extensions involving machine learning, ESG integration, financial distress prediction, and sector/macroeconomic conditioning.

One of the primary conclusions emerging from this review is the robust international effectiveness of the Piotroski F-score strategy. Its capacity to identify profitable investment opportunities—particularly among value stocks—has been consistently documented across a broad spectrum of markets, encompassing both developed economies and emerging markets (Walkshäusl, 2020). This cross-market resilience indicates that the F-score captures fundamental principles of financial statement analysis that transcend local institutional, regulatory, and informational differences, underscoring its value as a universally applicable tool in global equity investing.

This conclusion must, however, be tempered by notable exceptions that challenge the notion of unqualified universality. Evidence from the United Kingdom reveals the intriguing finding that the Piotroski F-score performs more effectively among growth stocks than traditional value stocks (Rathjens, Schellhove, 2011). Similarly, on the Polish market, the strategy failed to generate any significant value added over the examined period, with high F-score firms actually underperforming the broader value portfolio (Pilch, 2022, 2023). These anomalous results highlight potential moderating influences, including differences in informational efficiency, market microstructure, and investor behavior. In highly efficient and mature markets like the UK, basic accounting signals may be rapidly incorporated into prices, diminishing their predictive edge within the value segment. In contrast, the unique composition of listed firms in Poland during the sample period—potentially characterized by distinct ownership structures or sector concentrations—may have undermined certain core assumptions of the strategy. Overall, these findings caution against the mechanical cross-market application of the F-score without careful consideration of local contextual factors.

A central theoretical debate surrounding the Piotroski F-score concerns the economic origins of its abnormal returns. The accumulated empirical evidence predominantly supports the mispricing hypothesis, presenting an enduring challenge to the Efficient Market Hypothesis (EMH). Under this behavioral interpretation, the F-score premium arises from systematic investor expectation errors—particularly excessive pessimism toward distressed value firms—and the delayed incorporation of publicly available fundamental information into stock prices. Key studies, including Piotroski and So (2012) and Lopes and Galdi (2006), demonstrate that markets underreact to signals of financial improvement among high book-to-market stocks, allowing the F-score to systematically identify firms poised for positive earnings and price revisions. By exploiting this sluggish adjustment process, the strategy enables investors to capture returns that reflect the gradual correction of initial mispricing rather than compensation for heightened systematic risk.

In contrast, support for the risk-based explanation remains considerably weaker. The majority of studies find that conventional asset pricing models—such as the Fama-French three- or five-factor models—fail to fully account for the observed abnormal returns generated by the Piotroski F-score strategy (e.g., Walkshäusl, 2020). Furthermore, high F-score firms are, by construction, characterized by stronger fundamentals, including lower financial leverage, higher profitability, and improved operating efficiency—attributes that directly contradict the notion of elevated systematic risk exposure. One notable exception is the Australian market, where Hyde (2018) documents that much of the premium can be attributed to loadings on established risk factors (size, value, and momentum).

Over more than two decades, the Piotroski F-score has evolved from a specialized tool designed to refine value investing strategies into a broadly recognized indicator of firm fundamental strength. Contemporary extensions of the approach significantly expand upon the original framework, incorporating advanced methodologies and broader applications—as illustrated by the comparative overview in Table 3.

Table 3.
Comparison of the Original Piotroski F-Score Strategy and Contemporary Adaptations

Criterion	Original strategy (Piotroski, 2000)	Contemporary Adaptations
Stock Universe	Restricted to high book-to-market (B/M) firms	Extended to the broader market universe, including growth stocks and all listed firms, particularly on smaller or emerging markets.
Integration with Other Factors	Employed as a standalone selection filter	Frequently incorporated as a complementary signal in multifactor or hybrid strategies (e.g., combined with price momentum or machine learning models such as neural networks).
Consideration of Macroeconomic Environment	No explicit formal analysis	Increasingly accounts for macroeconomic regimes, business cycles, and monetary policy influences.
Selection Thresholds	Long positions in firms with F-scores of 8-9; short positions in firms with F-scores of 0-1	More flexible thresholds, commonly long positions in F-scores of 7-9 and short positions in F-scores of 0-2, to accommodate portfolio diversification and market-specific constraints.

Source: Author's elaboration.

Despite its conceptual appeal and empirical robustness, the Piotroski F-score strategy encounters substantial practical limitations in implementation. As Krauss et al. (2015) demonstrate, the strategy's performance is most pronounced among small-cap stocks, which typically exhibit low liquidity and elevated transaction costs. The findings of numerous studies indicate that the discriminatory power of the F-Score is inversely proportional to the size of the company. Hyde (2018) demonstrated that, in the Australian market, the monthly premium for small companies (1.36%) was almost twice as high as for large companies (0.85%). Drawing parallels with the Chinese market reveals analogous inferences. Deng's (2016) observations in this regard point to a discernible accumulation of premiums within companies exhibiting minimal analytical coverage. This finding aligns closely with the tenets of the investor neglect hypothesis. As Arbel and Strebel (1982) observe, the rarity of analysis of smaller entities means that price inefficiencies can persist for protracted periods. These frictions can materially erode—or even eliminate—theoretical gross returns, rendering the approach particularly challenging for large institutional investors constrained by scale and capacity concerns. Similar implementation hurdles, including bid-ask spreads and market impact costs, have been noted across various international markets, further underscoring the gap between theoretical efficacy and realizable net performance.

6. Summary

This comprehensive literature review conclusively demonstrates the enduring effectiveness and significance of the Piotroski F-score strategy. More than two decades after its introduction, the approach continues to serve as a cornerstone of contemporary fundamental analysis, exhibiting remarkable robustness and adaptability in identifying profitable investment opportunities across diverse market contexts.

The principal conclusions drawn from this literature review can be summarized as follows:

- **Broad Cross-Market Applicability:** Empirical research consistently affirms the Piotroski F-score as a globally robust tool, with Walkshäusl (2020) providing compelling evidence across 35 developed and emerging markets. The strategy's effectiveness has been validated in highly diverse settings, including the United States, Germany, the Nordic countries, China, India, Turkey, and South Africa. This widespread resilience suggests that the nine underlying fundamental signals effectively capture improvements in financial health, transcending local institutional, regulatory, and informational differences.
- **Size and Liquidity Effects:** A recurring finding across studies is that the Piotroski F-score strategy generates the strongest returns among small- and medium-sized firms, particularly those characterized by low liquidity and limited (or absent) analyst

coverage. This pattern indicates that the F-score is most effective in segments where informational inefficiencies are prevalent, allowing it to exploit investor underreaction to publicly available fundamental signals in less-followed stocks.

- **Enhancement of Complementary Investment Strategies:** The Piotroski F-score functions not only as an effective standalone selection criterion but also as a powerful overlay for augmenting other investment approaches. Empirical evidence indicates that incorporating the F-score as an additional filter substantially improves the risk-adjusted performance of portfolios constructed on accounting-based anomalies (Pătări et al., 2022) and hybrid strategies combining value characteristics with price momentum (Kupiainen, 2024). This synergistic effect underscores the F-score's versatility in refining broader fundamental and multifactor frameworks.
- **Sensitivity to Macroeconomic Conditions:** The predictive power of the Piotroski F-score strategy, as well as the underlying financial health signals it measures, exhibits notable sensitivity to prevailing macroeconomic conditions. Anderson et al. (2021) document that macroeconomic factors—particularly monetary policy—exert a substantially stronger influence on firms' fundamental signals (and thus F-scores) during economic recessions than expansions. This finding underscores the heightened salience of financial strength indicators in adverse environments, where external economic pressures amplify the discriminatory power of the F-score in separating resilient firms from vulnerable ones.
- **Role in Identifying Mispricing:** The core strength of the Piotroski F-score lies in its ability to detect systematic errors in investor expectations, consistent with the behavioral evidence presented in Piotroski and So (2012). By distinguishing fundamentally robust value firms—whose improvement potential is often underappreciated by the market—from financially deteriorating growth stocks that may be overvalued, the F-score enables investors to exploit mispricing opportunities. In particular, it serves as an effective safeguard against "value traps," allowing for more informed portfolio decisions that prioritize genuine financial recovery over superficial undervaluation.

More than two decades after its initial publication, the Piotroski F-score remains a robust and versatile cornerstone in the toolkit of fundamental investors. Its capacity to generate substantial value added through a straightforward yet powerful analysis of financial statement data has been consistently validated across a wide array of global equity markets, affirming its enduring relevance and practical utility in contemporary investment practice.

Regarding future research directions, the literature points to several promising areas. First, there is considerable scope for further developing F-score modifications through machine learning and artificial intelligence techniques, potentially yielding more adaptive and predictive variants. Second, additional studies are needed to examine in greater detail how macroeconomic regimes—including business cycles and monetary policy shifts—as well as transaction frictions (such as liquidity constraints and costs) influence the strategy's net profitability in real-world

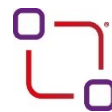
settings. Finally, deeper behavioral investigations into the psychological mechanisms underlying slow information diffusion would strengthen the theoretical underpinnings of the mispricing anomalies that the Piotroski F-score effectively exploits.

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IMPLEMENTATION OF THE "SMART CITY" CONCEPT – BEST PRACTICES OF POLISH CITIES, E.G. WARSAW AND WROCLAW

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Purpose: The aim of the article is to analyze and evaluate best practices in implementing the “smart city” concept in selected Polish cities, with particular emphasis on Warsaw and Wrocław, as well as to identify factors contributing to the effective implementation of “smart city” solutions and the challenges associated with it.

Design/methodology/approach: The research methodology includes triangulation of approaches such as analysis of strategic documents of the cities studied (including development strategies, digitalization programs and transport policies), a literature review on the "smart city" concept, including public information queries, and a qualitative case study of the cities of Warsaw and Wrocław.

Findings: The essence and assumptions of the "smart city" concept were explored. Using Warsaw and Wrocław as best-practice examples, methods for implementing the researched concept were identified. Based on this, the transformation processes in both cases towards a smart city were assessed. The strengths of both cities' practices were identified and key strategic challenges related to the phenomenon under study were identified.

Research limitations/implications: As "smart city" leaders, Warsaw and Wrocław can promote good practices at the national level, influencing regulations regarding the digitization of public services, autonomous transport, urban sensors, and infrastructure cybersecurity. The experiences of these cities provide valuable case studies for other metropolises aspiring to become smart and resilient.

Social implications: Identified practices of implementing the "smart city" concept led to an improvement in the quality of life of residents, increased social participation and transparency of city activities, but at the same time carry the risk of deepening digital inequalities.

Originality/value: Deepening and updating knowledge on sustainable urban development based on the assumptions of the "smart city" concept. Popularizing activities related to the studied phenomenon.

Keywords: smart city, digital transformation, best practices, Warsaw, Wrocław.

Category of paper: A literature review and case study.

1. Introduction

In an era of dynamic development of digital technologies and increasing urbanization, modern cities face the need to implement innovative solutions that enable effective management of urban space, resources, and services for residents (Bibri, Alexandre, Sharifi, 2023; Mazzetto, 2024). The "smart city" concept is becoming one of the key directions in the development of urban planning and management, combining information and communication technologies (ICT) with the concepts of sustainable development and social participation.

In Poland, the implementation of the "smart city" concept is gaining momentum, primarily in large metropolitan areas such as Warsaw and Wrocław, which serve as examples of cities undertaking systemic actions to digitize urban infrastructure, improve the quality of life of residents, and increase the efficiency of public administration (Marchlewska-Patyk, 2023).

This article presents a comprehensive analysis of the implementation of the "smart city" concept, based on the examples of the two largest and most technologically advanced cities in Poland: Warsaw and Wrocław. Unlike many works based primarily on theoretical studies or analyses of international concepts, this study focuses on practical solutions implemented in the Polish socio-economic context, considering local specifics, institutional conditions, and the country's level of digitalization.

The article also provides a comparative assessment of the actions undertaken by two cities with different structures and development strategies, allowing for the identification of both common elements and unique approaches to implementing the smart city concept. This type of analysis rarely appears in literature, which usually describes individual cases or focuses on Western European cities.

The text's originality also lies in the integration of data from various sources—strategic documents, city reports, available digital data, and descriptions of implemented technologies. This approach allows not only for the presentation of the most important "smart city" projects but also for the assessment of their effectiveness, progress, and impact on residents' quality of life.

The article also adds value by presenting practical implications stemming from the experiences of Warsaw and Wrocław, which can serve as a benchmark for other Polish and European cities planning development in line with the "smart city" concept. The publication thus offers an original contribution to literature, combining an academic perspective with a practical approach to urban transformation processes.

The research methodology used in the study includes triangulation of such approaches as: analysis of strategic documents of the studied cities (including development strategies, digitalization programs and transport policies), a review of literature on the "smart city" concept, including public information queries, and a qualitative case study of the cities of Warsaw and Wrocław.

2. Literature review

Based on a review of scientific literature, the essence of the “smart city” concept and the factors justifying its implementation by urban agglomerations were analyzed. These categories were considered key to describing and identifying the practices of the cities studied.

2.1. The concept of a “smart city” – definition, stages of development

Initially, the concept of a "smart city" focused primarily on implementing advanced technical infrastructure, such as intelligent transportation systems and environmental monitoring (Giffinger et al., 2007). Over time, its meaning has evolved from a technological "city of the future" to a holistic model in which public participation, data integration, responsible management, and attention to social and environmental aspects also play a key role (Clark, 2020). This process is confirmed by the overview of selected definitions of the "smart city" concept presented in Table 1, which shows how its understanding has changed over time.

Table 1.
Comparative of Smart City Definitions

Author of the definition	Definition	Key Focus/Dimensions
Giffinger et al. (2007)	„Smart City is a city performing well in six key dimensions: economy, people, governance, mobility, environment, and quality of life”	six-dimension model (economic, human, governance, environmental, mobility, QoL)
Hollands (2008)	„A Smart City relies on ICT but must also critically examine the social impacts of technology and support citizen inclusion”	critical perspective, social justice, citizen empowerment.
Caragliu, Del Bo, Nijkamp (2011)	„A city is smart when it invests in human and social capital, ICT infrastructure, and sustainable development to enhance quality of life and resource management”	human capital + social capital + ICT + sustainability
Nam, Pardo (2011)	„Smart City emerges from the integration of technology, people, and institutions, creating innovative urban services”	three pillars: technology, people, institutions.
Townsend (2013)	„A Smart City uses digital technologies and data to support innovation, collaboration, and improve urban life”	data-driven innovation, civic tech, collaboration
Komninos (2013)	„Smart Cities are innovation territories where knowledge, creativity, and technology interact to produce intelligent solutions”	knowledge-based development, creativity, innovation ecosystems
ISO 37122 (2019)	„Smart Cities systematically use digital technologies to improve performance across key urban domains using standardized indicators”	measurement, performance indicators, digital systems.
Bibri, Krogstie (2020)	„Smart Cities are data-driven urban systems using AI, IoT and Big Data to improve sustainability, efficiency, and quality of life”	AI + IoT + Big Data; sustainability and optimization
OECD (2020)	„Smart City uses digital technologies to design and deliver better public policies while ensuring inclusiveness, transparency, and ethical data use”	governance, inclusiveness, ethics, public value
European Commission (2020)	„Smart City applies innovative technologies and data to improve sustainability, energy efficiency, and public services”	innovation, sustainability, energy efficiency

Source: Prepared based on the sources given on the table.

The comparative overview of “smart city” definitions demonstrates that the concept has evolved from a predominantly technology-centered vision toward a more holistic and citizen-oriented approach. Early frameworks, such as those by Giffinger et al. (2007) and Caragliu & Nijkamp (2011), emphasize the role of ICT, human capital, and sustainable development, while later perspectives increasingly integrate data-driven governance, ethical considerations, and social inclusiveness (OECD, 2020; ISO, 2019; Bibri, Krogstie, 2020). The table highlights that although terminology varies, all definitions converge on the idea that a “smart city” leverages innovation and digital tools to enhance the quality of life and urban performance. At the same time, authors such as Hollands underline the importance of critically assessing technological impacts to ensure cities remain equitable and human centered.

2.2. Factors justifying the need to develop the “smart city” concept

Various factors justify the need to develop the concept of a “smart city”. However, in the opinion of many authors (e.g. Albino, Berardi, Dangelico; 2015; Czupich, Ignasiak-Szulc, Kola-Bezka, 2016; Sharifi et al., 2024) - the biggest factors affecting its implementation are: congestion, environmental pollution, and public safety.

The first of these factors, congestion, relates to the growing population in cities and the associated increase in the number of cars. The importance and essence of this problem from the point of view of smart urban development is explained, among others, by Duranton & Turner (2011), Newman & Kenworthy (2015), Kumar et al. (2020). Growing congestion in large cities is leading to increased demand for more efficient, intelligently managed road infrastructure that can meet user expectations and cope with actual traffic volumes. This solution allows for efficient movement around the city, reduces traffic jams, and improves traffic flow (UN-Habitat, 2020).

The second important factor confirming the need to develop the “smart city” concept is the environmental pollution observed in recent years. The World Health Organization (WHO) emphasizes in numerous reports (2016-2023) that road transport is the main source of pollution in cities. Due to the increasing emissions of exhaust fumes and other harmful substances, fog, smog, heavier rainfall, and even the creation of a unique microclimate with winds blowing from central districts towards the suburbs and temperatures often more than 10 degrees higher than in the surrounding areas have become increasingly common. Poor air quality directly affects the residents of many cities. This fact makes them feel worse and even suffer from serious illnesses, the treatment of which is very costly. Additionally, it is worth noting that the larger the population, the more waste is generated, and improper waste management leads to environmental degradation (Sztangret, Reformat 2020). Growing environmental pollution in cities points to the need to implement modern, smart solutions that will enable more effective monitoring, reduction, and management of emissions, as well as improve the quality of life for residents.

The third important factor supporting the need to develop the “smart city” concept is public safety (Zawartka, 2024). The large number of city dwellers and their diversity have led to an increase in crime in these areas. Initially, people settling in these areas did not establish contact with each other, feeling alienated, and therefore believed that they were anonymous in the local community. Contemporary cities are becoming increasingly complex organisms, bringing together large numbers of residents, critical infrastructure, and diverse social processes. Increased urbanization leads to greater risks associated with crime, accidents, traffic hazards, and emergencies such as fires, floods, and infrastructure failures (Łuczyszyn, 2017). For this reason, cities must implement solutions based on modern technologies that enable rapid detection, analysis, and effective response to threats. Artificial intelligence-based monitoring systems, smart lighting that improves visibility and safety, sensors that detect anomalies, alarm applications, and crisis management centers that integrate data in real time are becoming key elements of a “smart city” (Muntean, 2024). These technologies not only reduce the number of dangerous incidents, but also increase residents' sense of safety, which is one of the foundations of quality of life in the city.

To sum up the above discussion, it should be emphasized that the factors presented above have the greatest impact on the development of the “smart city” concept. At the same time, it should be borne in mind that advances in information technology and changes in the needs of city dwellers related to improving their quality of life are the main determinants of the evolution of this concept.

3. Methods

3.1. Theoretical Foundations

The article focuses on the concept of the “smart city,” which promotes the creation of friendly living conditions for residents of large and medium-sized urban areas. The main research problem is included in the question: *How can the experiences of Warsaw and Wrocław serve as a model for other cities in Poland in the process of digitalization and intelligent management?* To identify the phenomenon under study, qualitative research of a diagnosis nature was carried out. The aim of the study was to analyze and evaluate the implementation of the "smart city" concept in Polish cities, using Warsaw and Wrocław as examples, considering best practices and challenges. The author focused on identifying key areas of the concept, such as mobility, energy, the environment, public e-services, security, and social participation. The adopted goal determined the choice of research methodology, which included the triangulation of such approaches as: analysis of strategic documents of the studied cities (including development strategies, digitalization programs and transport policy), a review of

literature on the concept of a "smart city", including public information queries and a qualitative case study of the cities of Warsaw and Wroclaw. The methods used enabled a multi-aspect assessment of the transformation processes of both cases towards a "smart city". Basic information on the survey conducted is presented in Table 2.

Table 2.

Basic information on the survey conducted

Specification	Characteristic
Research methodology	- the analysis of specialized journals, materials on the studied city, websites, participant observation, case study.
Sample selection	- targeted selection, - criterion: best practices in the field of the phenomenon under study.
Sample size	- best practices in the field of the examined phenomenon selected based on the "Smart City Index 2024/25" Ranking and the "European Cities & Regions of the Future 2025" Ranking, - two cities: Warsaw & Wroclaw.
Geographical scope	- national scale.
Time scope	- 2020-2025.

Source: own elaboration.

3.2. Research Methods

The methods used in the article enabled a multi-aspect assessment of the transformation processes of both cases towards a smart city. They also allowed us to identify actions necessary to increase the efficiency and coherence of "smart city" solutions in the future.

The identification of the studied examples of Polish cities, reflecting the best practices in implementing the "smart city" concept, was based on the analysis of the results of the two latest rankings regarding the studied phenomenon. The first of them was the "Smart City Index" ranking published by the Swiss Business School in Lausanne (IMD) in cooperation with the Singapore University of Technology and Design (IMD, 2025). Cities from this ranking were rated on a scale from A (best grade) to D, and the ranking included two main categories: infrastructure and technologies divided into health and safety, transport, work and science, and city management. It should be added that this ranking was based primarily on the opinions and observations of city residents, but experts also analyzed the way in which technology improves the lives of their citizens. The second source of information was the prestigious European Cities & Regions of the Future 2025 Ranking, prepared by fDi Intelligence - an opinion-forming magazine belonging to the British daily "The Financial Times".

Based on the above-mentioned requirements, rankings identified the two most "smart city" in Poland, which are: Warsaw and Wroclaw¹. These cities implement solutions that not only modernize urban space, but also become an inspiration for other local governments, so they can be considered best practices in the implementation of the "smart city" concept.

¹ It is worth adding that, apart from Warsaw and Wroclaw, the top five smartest cities in Poland also include: Kraków, Poznan and Gdansk.

4. Results

4.1. Practice I – City of Warsaw

According to the “Smart City Index 2025” ranking (IMD, 2025), Warsaw was ranked 28th out of 146 cities in the world. The city received a high score in two dimensions of the ranking: "urban structures" and "digital technologies", which shows the sustainable development of infrastructure and digitalization. The ranging results revealed that significantly influenced by the attitudes of the residents themselves, which reflect a high level of digital social maturity. The city is not only developing infrastructure and services – it also has users who are ready to consciously engage with them. Data collected as part of the study shows that 75.8% of Warsaw residents regularly use cashless payments, demonstrating the widespread adoption of modern transaction methods and openness to digital solutions in everyday life. Additionally, 55.1% of residents believe that easy access to public information increases their trust in the authorities – an important indication that transparency and digitalization of administration translate into positive public perception. It is also worth noting that 51.3% of respondents accept the use of city data for purposes such as reducing traffic congestion, confirming growing understanding of data-driven initiatives and managing the city in an automated yet thoughtful manner. All this together forms a foundation for the continued development of the city as a modern, open, and functional metropolis (IMD, 2025). The strategy for the development of Warsaw as a “smart city” assumes strong digitization of administration and the implementation of innovative urban solutions in several specific areas - see Table 3.

Table 3.

Areas of the strategy for the development of Warsaw as a “smart city” assuming strong digitization of administration and the implementation of innovative urban solutions

“Smart city” development area	The essence, purpose and assumptions of the area
Politics digital transformation	- assumes the automation of official processes and digitization of administrative resources, as well as the use of big data for the processing of large data sets for better city management, - indicates, among others, on such values as: transparency, openness, 24/7 access to services, and cloud computing that supports the integration of urban, - the aim is to improve public services, including improving their quality and accessibility for residents, and creating platforms that will centralize data and services (e.g. a specific “Internet of Things” (IoT) platform collecting real-time data from sensors in the city, enabling better management of urban infrastructure), - the city is also planning other platforms: including: a platform for communication with residents, a platform for sharing data, and for providing services, - the main values of the transformation are usefulness, efficiency and inclusiveness.

Cont. table 3.

E-services for residents	- one of the key projects is the Municipal Contact Center 19115 (Warsaw 19115) it is a channel through which residents can report issues, communicate with the office, etc., - with the development of the office's digitization, the mojaWARSZAWA platform (mojaWarszawa19115) was launched, which enables handling many matters completely online (e-services), - dozens of e-services are currently available in the system: from administrative matters, through information on garbage collection, to air quality data.
Usage Internet of Things (IoT)	- launching an IoT platform collecting data from sensors located in the city (e.g. air quality sensors, number of free parking spaces, location of toilets, etc.), - integration of IoT data with urban open data platforms, which promotes analysis and innovation.
Ethical use of artificial intelligence	- the city's adoption of "Directions for the responsible use of generative AI" in public administration, - introduction of the "Warsaw GenAI Code" containing transparency guidelines and ethical principles for the use of AI in the city hall.
Innovations in strategy – "We Generate Innovations Program"	- executive program for 2021-2025, its idea fits into the strategic goal "Creative environment", which includes, among others: supporting entrepreneurship, urban startups, - use of new technologies, cooperation between the public and private sectors, - the program diagnosis indicates the need to build Warsaw's innovative potential and increase the share of digital technologies in the city's everyday functions.
Cybersecurity and digital infrastructure	- Warsaw is also developing cybersecurity structures, - there is a metropolitan model of digital security, - Information Technology (IT) Office of the Capital City Office Warsaw is responsible for technology coordination, implementation of IT systems, cloud infrastructure management and development of urban IT architecture.

Source: on based (Polityka cyfrowej transformacji...; Strategia #Warszawa2030 ...; Metropolitalny CSO...).

The "smart city" strategy for the development of Warsaw, based on digitalization and innovation, directs the city to build a modern, flexible and resident-friendly ecosystem of public services. The integration of advanced technologies with urban management is intended not only to improve the functioning of administration, but also to improve the quality of life, increase transparency and enable more conscious and participatory co-creation of urban policies. Thanks to this, Warsaw could strengthen its position as an intelligent metropolis, able to quickly respond to the challenges of the future and create sustainable development based on data, cooperation and innovation.

4.2. Practice II – City of Wrocław

Or several years, Wrocław has been consistently developing into a modern, intelligent metropolis that uses digital technologies to improve the quality of life of its residents and improve city management. Its achievements are confirmed by the results of the prestigious European Cities & Regions of the Future 2025 ranking. The data presented in it shows that Wrocław not only took first place in the category of medium-sized European cities but also became a leader in terms of business-friendliness and human capital and the best place to live. It was also awarded second place among the cities with the greatest economic potential (Karpecka, 2025).

The implementation of the "smart city" concept in the case of Wrocław is based on the integration of innovative tools, urban data and cooperation with residents, which allows to create a more effective, sustainable and friendly urban environment (*Wrocław 2030 Strategy...*). Thanks to numerous projects in the areas of mobility, ecology, e-administration and security, Wrocław is becoming an example of a city that actively uses the potential of technology to respond to modern challenges and shape dynamic urban development - see Table 4.

Table 4.

The most important areas in which Wrocław conducts "smart city" activities

Area "smart city" implementations	Applied solutions	Examples implementation
Mobility and intelligent transport	Intelligent ITS Traffic Management	- network of sensors, cameras and signaling controllers, - dynamic traffic light control (green waves, tram priorities), - passenger information boards displaying the arrival time of transport.
	Development of public transport	- electronic boards at bus stops, - applications showing the actual location of vehicles, - introduction of Urban Card as an integrated ticket system and city service card.
	Micromobility	- a rich network of city bikes and scooters, - expansion of bicycle routes and stands, - integration of travel planning (e.g. in multimodal applications).
E-services and digital administration	E- office, electronic inboxes and the ability to register visits to offices	- platform for submitting applications and fees online (including local taxes, registers, ID card applications).
	Open Data of Wrocław	- a portal with publicly available urban data sets (transport, environment, budget), made available to residents and technology companies.
Environment and intelligent infrastructure	Monitoring environmental	- network of air quality sensors, - real-time pollution analysis, - online data publication.
	Energy and lighting management	- modern LED lighting in public spaces, controlled depending on traffic intensity, - intelligent energy management systems in municipal buildings.
	Water management and green infrastructure	- solutions to counteract floods and droughts (retention, urban greenery), - digital monitoring of river and canal levels.
Participation and co-management of the city	Budget Civic	- residents submit projects and decide on part of the city's expenses. - digital voting and consultation platforms.
	Applications reporting	- ability to report faults, failures and needs in public space, - quick reactions of city services thanks to digital information flow.
	Wrocław's Housing Estate Council	- digital cooperation between residents and officials, - online consultations regarding local plans, transport and investments.
Smart governance – data-based management	Big Data and analytics	- analysis of traffic and transport behavior of residents, - urban modeling using spatial data (GIS), - monitoring the effectiveness of city services.

Cont. table 4.

Culture, education and intelligent social services	Using technology in soft areas	- digital libraries, e-book rentals, - educational applications and school support tools. - smart solutions in cultural institutions (online reservations, virtual tours) - development of startups and academic projects thanks to cooperation with the Wrocław University of Science and Technology and the University of Warsaw
Wrocław as an innovation center	Initiatives supporting the knowledge-based economy	- Wrocław Technology Park, - Entrepreneurship and startup accelerators, - investment zones and cooperation with companies from the IT, R&D and AI industries, - numerous hackathons and open-source projects based on urban data

Source: based on (Strategia rozwoju „Wrocław 2050”...).

The presented analysis shows that Wrocław, as an example of a city implementing the "smart city" concept, strategically uses technologies to make life easier for its residents, improve the quality of public services, increase the transparency of local government activities, develop an economy based on innovation and care for the environment and sustainable development.

5. Discussion

The "smart city" concept assumes the use of technology, data and modern organizational solutions to increase the efficiency of the city, improve the quality of life of residents and sustainable development. It turns out that in practice, the implementation of this idea may look very different, which is confirmed by the analysis of the two best business practices in Poland presented. They depend on local strategies, needs, resources and priorities of city authorities. A comparative analysis of the practices of Warsaw and Wrocław showed how these two large Polish cities implement the "smart city" concept, what areas of development they choose and what challenges they face.

Warsaw adopted the "Policy of digital transformation of the capital city of Warsaw", a strategic document defining the directions of the city's technological development. In the "Smart City" strategy, the key areas are intelligent mobility, city management, human capital, quality of life, environmental protection and sustainable infrastructure (*Warsaw towards Smart City...*). The city is creating a data ecosystem - the Warsaw IoT Platform collects data from city sensors, and the "Open Data in Warsaw" project makes it available to citizens (*Warsaw IoT Platform...*). Research on city resilience often uses the resiliency model² (e.g. Newell, Stults, 2016). In the "smart city" concept, Warsaw adapts the resilience model to

² The resilience model shows how a person or system survives difficulties, adapts to them and emerges stronger from them.

better respond to crises and uncertainty. These observations are consistent with the results of analyzes conducted by Baran, Kłos & Marchlewska-Patyk (2022).

In turn, Wrocław is implementing the innovative "Smart City Wrocław" Program, which covers five main areas: seniors and disabled people, intelligent transport, SMEs, education and security and crisis management. The city emphasizes the role of open data through the "Open Data Wrocław" website, which allows residents and entrepreneurs access to city data sets. The analysis of the "Wrocław 2050" strategy shows that the city envisages the integration of "smart city" systems: optimization of the energy and transport networks, water and sewage systems, and monitoring of weather threats. The "smart city" strategy covers six equivalent areas: mobility, economy, environmental resources management, human capital, quality of life and city management. The CityLab initiative enables startups and scientists to test innovative solutions in urban space (e.g. technologies related to transport and emissions).

The analysis carried out allowed for a comparison of activities carried out by both cities in specific "smart city" areas - see Table 5.

Table 5.

Comparative analysis of activities implemented by Warsaw and Wrocław in specific "smart city" areas

"Smart city" area	Warsaw	Wrocław
Mobility and transport	- development of public transport, integration of city cards, use of IoT and sensors in public transport systems.	- priority on intelligent transport (ITS), mobile applications (e.g. Vozilla), testing solutions in CityLab.
Digital services and e-government	- city platforms (e.g. Moja Warszawa), resident reporting systems (19115 application), city data analytics.	- e-document management, queuing system, applications supporting residents (Mobile Assistant, Virtual Advisor).
Open access to data	- IoT platform and open data that is shared widely, in various formats.	- Open Data Wrocław website, the city strives to maximize data democratization.
Environmental and energy management	- investments in energy efficiency, modern urban infrastructure systems, intelligent resource management.	- systems for optimizing energy networks, greenery and resource management through data and predictive technologies.
Residents' involvement	- strong emphasis on participation, transparency and co-decision, "smart city" strategies are designed considering the needs of citizens.	- city laboratories (CityLab), testing activities, cooperation with entrepreneurs and residents in creating urban innovations.
Financing and partnerships	- data-based management models, city resilience models, city support for innovative projects, administration.	- public-private partnerships, startups, cooperation with global companies (e.g. Nokia), financing of test projects at CityLab.

Source: Own study based on conducted analyses.

The comparative analysis of the activities of both cities allows us to see their strengths and challenges related to the implementation of the "smart city" concept. In the case of Warsaw, the strengths include:

- a) an extensive digital transformation strategy, a coherent vision of "smart city" activities,
- b) strong data infrastructure (IoT, open data), which enables advanced analytics and optimization of urban processes,

- c) high participation of residents, which allows us to adapt services to the real needs of the city,
- d) resilience model, which assumes responding to crises, which increases the city's flexibility.

Referring to the city of Wrocław, the strengths of implementing the "smart city" concept include:

- a) a wide range of areas (6 equivalent) of "smart city" activities, which ensures even development of the city,
- b) flexibility obtained with the help of CityLab - testing new technologies in urban practice, cooperation with startups,
- c) strong emphasis on open data and transparency of city activities d) integration of technology,
- d) with long-term planning (vision Wrocław 2050).

Summary

The aim of this article, which was to analyze and evaluate the implementation of the "smart city" concept in Polish cities, using Warsaw and Wrocław as examples, considering best practices and challenges, was to demonstrate that Warsaw and Wrocław represent two strong, yet somewhat different, models for implementing the "smart city" concept.

Based on the achieved objective of the article, certain theoretical and practical implications of its content can be identified. In terms of theoretical implications, firstly, the article deepens our understanding of what a smart city is, demonstrating that it is not limited solely to ICT technologies but also encompasses governance, resident participation, sustainable development, and mobility. The analysis of Warsaw and Wrocław demonstrates that the "smart city" concept must be adapted to the regional context rather than thoughtlessly transferred (it depends on the cities' circumstances, budgets, investments, local community openness to innovation, etc.). Thirdly, empirical material illustrating best practices in the development of Polish cities can help build city-specific implementation models at the national level. At the same time, the practices of Warsaw and Wrocław emphasize the importance of cross-sectoral cooperation (local government, businesses, and residents), open data, and the digitization of public services. Another theoretical implication suggests that "smart city" theories should more closely consider governance and co-management, not just technology.

Regarding practical implications, it should be noted that the discussed case studies of Warsaw and Wrocław identified practical tools (including Intelligent Transportation Systems, city applications and e-service platforms, air quality monitoring systems, smart lighting, and open data) they use. Other cities can therefore draw on ready-made solutions and

mechanisms for implementing the "smart city" concept. This knowledge can also serve as a guide for decision-makers to prepare "smart city" strategies. Local governments can also use this knowledge to improve administrative efficiency – the cities studied demonstrate how technologies support urban resource management, decision-making (including predictive analytics), and communication with residents. The article provides best practice models that can be compared, adapted, and assessed for effectiveness in other contexts, thus creating the possibility of benchmarking for other cities.

The author is aware of the limitations of the conducted analysis, which was based primarily on publicly available strategies and documents, meaning that lesser-known local or pilot projects were not included. Another limitation is the lack of a more detailed analysis of direct, comparable financial reports for all "smart city" projects in both cities, to assess their cost-effectiveness. However, these limitations open room for further analysis and research on the issues addressed in this article.

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STRATEGIES FOR REDUCING AND VALORIZING INDUSTRIAL WASTE IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT AND INDUSTRY 4.0

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Purpose: The purpose of this paper is to synthesize current strategies and technological solutions for the reduction, processing, and valorization of industrial waste within sustainable development and Industry 4.0 frameworks, focusing particularly on Poland's heavy industry context. The analysis critically identifies implementation barriers and opportunities from digital innovations and circular economy principles.

Design/methodology/approach: The literature review encompasses preventive strategies (process optimization, eco-design, cleaner production), advanced waste processing methods (physical, chemical, thermal, biological), and systemic circular approaches (industrial symbiosis, upcycling, integrated waste management). Digital technologies—IIoT, digital twins, AI/ML—are evaluated for material flow optimization, drawing on recent publications, ISO standards, and UNEP reports with critical Discussion analysis.

Findings: Effective waste management requires integrated source prevention, advanced valorization, and digital optimization. CE concepts reframe waste as resources while Poland faces sector-specific challenges (mining, metallurgy) requiring EU-aligned transformation. Barriers including competency gaps and data deficits are addressable through policy and collaboration, as detailed through critical literature evaluation.

Originality/value: This systematic Polish-context synthesis of prevention-processing-digitalization critically evaluates literature limitations, identifies heavy industry barriers, and proposes research priorities (LCA, symbiosis models, decision tools), offering managers and policymakers practical implementation roadmaps for EU-compliant circular transformation.

Keywords: Industrial waste management, Circular economy, Waste valorization, Industry 4.0 technologies, Sustainable development.

Category of the paper: Literature review.

1. Introduction

Industrial activities are among the main drivers of global resource extraction and waste generation, contributing significantly to greenhouse gas emissions, ecosystem degradation, and pressures on human health. In the European Union alone, industrial sectors such as manufacturing, construction, and energy production generate hundreds of millions of tons of waste annually, much of which is still landfilled or downcycled despite growing regulatory and societal pressure to improve circularity. In countries with a strong industrial base such as Poland, where sectors including mining, metallurgy, chemicals, and manufacturing play a key economic role, the challenge of industrial waste management is particularly pronounced due to legacy pollution, high material intensity, and the need to align with evolving EU environmental regulations, including the Green Deal and Waste Framework Directive. At the same time, volatile raw material prices, supply chain disruptions, and climate-related risks are forcing companies to reconsider traditional linear "take–make–dispose" models and to seek more resilient, resource-efficient production strategies (Semrau, 2025).

Sustainable development, as articulated by the Brundtland Commission, requires meeting present needs without compromising the ability of future generations to meet their own, which directly implies a profound transformation of how industrial waste is generated, managed, and valorized. Waste reduction at source, improvement of processing technologies, and the integration of circular economy principles are therefore not only environmental imperatives but also economic and social necessities for modern industry. In this context, technological innovations associated with Industry 4.0—such as the Industrial Internet of Things (IIoT), advanced analytics, digital twins, and artificial intelligence—offer new opportunities to monitor material flows, predict waste generation, and optimize process performance across the entire value chain.

Recent research highlights that effective industrial waste management must combine preventive approaches (eco-design, cleaner production), advanced treatment and valorization methods (physical, chemical, thermal, and biological), and systemic strategies such as industrial symbiosis, resource recovery, and integrated waste management systems. Circular economy concepts further promote the retention of material value through reuse, repair, remanufacturing, and high-quality recycling, supported by appropriate policy instruments and environmental management standards (e.g., ISO 14001). However, the practical implementation of these concepts at the plant and network levels remains challenging due to technological, organizational, and data-related barriers (Horzela-Miś, Semrau, 2025).

This paper systematically synthesizes current strategies and technological solutions for reducing, processing, and valorizing industrial waste in the context of sustainable development and Industry 4.0, with particular emphasis on Poland's heavy industry context. The analysis specifically examines: (I) optimization of technological processes for waste prevention,

(II) advanced methods for waste processing and energy/material recovery, (III) circular economy approaches including industrial symbiosis and upcycling, and (IV) the role of digital technologies and integrated management systems in enabling data-driven, systemic waste management. Through critical evaluation of literature limitations presented in the Discussion section, this review identifies key implementation barriers in transitional economies, proposes novel contributions for Central European contexts, and addresses three core research questions: Which integrated strategies prove most effective under EU regulatory constraints? What are the primary barriers to implementation in heavy industries like Poland's mining and metallurgy sectors? What research priorities—such as LCA assessments, symbiosis network modeling, and decision-support tools—will bridge existing theory-practice gaps?

The aim is to not only synthesize current trends but also highlight actionable opportunities for industrial stakeholders, policymakers, and researchers to enhance environmental performance and economic competitiveness through sustainable waste management practices that align with EU Green Deal objectives. By providing Poland-specific implementation frameworks and sequential transformation roadmaps detailed in the Conclusion, this paper bridges the gap between global literature insights and regional industrial transformation challenges.

2. Reduction of Industrial Waste in the Context of Sustainable Development

The reduction of industrial waste lies at the core of sustainable waste management strategies. By preventing waste generation at the source, industries can reduce environmental burdens, improve resource efficiency, and lower operational costs. Sustainable development, as defined by the Brundtland Commission (1987), emphasizes meeting present needs without compromising the ability of future generations to meet their own. In this context, reducing industrial waste is not merely an environmental imperative but a socio-economic necessity (Kuhlman, Farrington, 2010).

2.1. Optimization of Technological Processes

One of the most effective ways to reduce industrial waste is through the optimization of manufacturing and technological processes. Technological optimization involves streamlining production lines, improving process control, and adopting lean manufacturing principles to minimize raw material waste. For example, advanced sensors and automation systems allow real-time monitoring and adjustment of material flow, reducing overproduction and defects. Additionally, the integration of Industry 4.0 technologies, including the Industrial Internet of Things (IIoT), digital twins, and advanced analytics, has shown promise in forecasting waste generation and identifying inefficiencies in complex production systems.

The use of digital twins—virtual replicas of physical assets—enables simulations that model how process adjustments impact waste outputs, facilitating predictive maintenance and reducing downtime-related material losses. Predictive models based on artificial intelligence (AI) and machine learning (ML) algorithms can accurately predict where and when waste will occur, thus enabling proactive waste reduction (Alsabt et al., 2024).

2.2. Eco-Design and Sustainable Product Engineering

Eco-design, also known as Design for Environment (DfE), is a preventive approach that aims to minimize environmental impact through product design (Singhal et al., 2024). By selecting recyclable or biodegradable materials, reducing product complexity, and designing for disassembly, manufacturers can limit waste at the end of a product's life cycle. The approach known as Design for Disassembly (DfD) enables products to be easily dismantled so that parts can be reused, repaired, or recycled, extending material lifespans and reducing demand for virgin resources.

Moreover, lifecycle thinking is increasingly being integrated into industrial design practices. Lifecycle Assessment (LCA), a methodology standardized by the International Organization for Standardization (ISO 14040), allows for the quantitative assessment of environmental impacts associated with all stages of a product's life—from raw material extraction through production, use, and disposal.

2.3. Implementation of Cleaner Production Strategies

The United Nations Environment Programme (UNEP) defines Cleaner Production (CP) as "the continuous application of an integrated preventive environmental strategy to processes, products, and services to increase overall efficiency and reduce risks to humans and the environment" (UNEP, 2007). CP focuses on improving process efficiency, substituting hazardous inputs, and reducing waste and emissions before they are generated. Key CP practices include energy efficiency improvements, raw material substitution, and process intensification.

A UNEP report showed that implementing CP techniques in textile manufacturing led to noticeable reductions in chemical use and water consumption (UNEP, 2020). CP is considered superior to end-of-pipe solutions because it tackles the root causes of waste generation rather than treating symptoms.

3. Processing and Valorization of Industrial Waste

Where complete prevention of waste generation proves unfeasible despite preventive measures, the waste management hierarchy prioritizes its effective processing and recovery as the next critical step. Processing encompasses a range of techniques aimed at transforming waste streams into usable forms—such as secondary raw materials, energy carriers, or value-added products—thereby maximizing resource recovery rates and minimizing environmental impacts associated with disposal. Industrial waste processing methods are broadly classified into physical/mechanical (e.g., shredding, sorting, separation), chemical (e.g., neutralization, precipitation, extraction), and biological (e.g., composting, anaerobic digestion) categories, with increasingly popular hybrid approaches combining these for optimal treatment of complex, heterogeneous waste streams in modern applications (Alao et al., 2022). This strategic focus not only complies with regulatory frameworks like the EU Waste Framework Directive but also unlocks economic value through resource circularity and reduced landfill dependency.

3.1. Physical and Mechanical Processing

Physical processing methods aim to alter the physical characteristics of waste for easier handling, separation, or further treatment. These include size reduction (shredding, crushing), sorting, magnetic separation, flotation, and densification (e.g., briquetting or pelletizing). Such methods are particularly useful in the pre-treatment of construction and demolition waste, scrap metal, and mineral residues.

Advanced mechanical processing systems are now often equipped with automated sorting technologies, including near-infrared (NIR) sensors, eddy current separators, and computer vision, enabling accurate segregation of materials such as plastics, metals, and glass. This pre-processing is critical in preparing waste streams for high-quality recycling and contributes significantly to material recovery rates (Amobonye et al., 2023).

3.2. Chemical Processing and Thermal Treatment

Chemical processing methods use chemical reactions to treat or transform waste. These include neutralization, precipitation, oxidation-reduction reactions, and solvent extraction. Hazardous waste streams, such as heavy metal-containing sludges and halogenated solvents, are often stabilized through chemical immobilization techniques (Ragaert et al., 2017).

Thermal treatments such as incineration, pyrolysis, and gasification are widely employed for both hazardous and non-hazardous waste. Pyrolysis, in particular, has received increasing attention for its potential to convert polymer waste into synthetic fuels and valuable chemicals.

Gasification, which occurs at higher temperatures and with controlled oxygen, converts carbon-rich waste into synthesis gas (syngas), which can be used for power generation or chemical synthesis.

3.3. Biological Treatment of Industrial Waste

Biological methods utilize microorganisms to degrade or transform waste into less harmful forms. These are most applicable to biodegradable industrial waste such as food-processing sludge, paper mill effluents, and certain agricultural residues. The two most common biological processes are:

- Aerobic composting, where organic matter is decomposed in the presence of oxygen to produce stable humus-like material, and
- Anaerobic digestion (AD), where organic materials are broken down in oxygen-free conditions, producing biogas (a mix of methane and carbon dioxide) and digestate.

Anaerobic digestion of food industry by-products can yield up to 500 m³ of biogas per ton of organic matter, providing a renewable energy source while reducing the organic load in wastewater (Pilarska et al., 2023).

4. Circular Economy Approaches in Industrial Waste Management

The circular economy (CE) represents a systemic paradigm shift that fundamentally contrasts with the traditional linear economy model of "take–make–dispose," where resources are extracted, transformed into products, and ultimately discarded as waste. In the CE framework, the primary objective is to maximize the retention of value embedded in products, materials, and resources throughout their lifecycle by prioritizing strategies such as reuse, repair, remanufacturing, and high-quality recycling, thereby minimizing the need for virgin raw materials and reducing environmental externalities. Waste is reconceptualized not as an inevitable endpoint or liability, but as a valuable secondary resource that can be reintegrated into production cycles, fostering resource efficiency, lowering operational costs, and creating new economic opportunities through closed-loop systems (Naqvi et al., 2021). This approach aligns with broader sustainable development goals by decoupling economic growth from finite resource depletion and waste generation.

4.1. Industrial Symbiosis and Zero Waste Initiatives

Industrial symbiosis is a key CE strategy where the by-products or waste from one industrial process are used as inputs in another. The Kalundborg Symbiosis in Denmark is the most cited example, where excess heat, water, and by-products like gypsum and fly ash are shared among several companies, reducing the need for virgin inputs and lowering overall emissions.

Zero waste strategies aim for complete elimination of landfill disposal by maximizing reuse, recycling, and recovery. These strategies often involve redesigning production systems to close material loops and eliminate inefficiencies. Implementation may include extended producer responsibility (EPR) policies, material passports, and take-back programs (Valentine, 2016).

4.2. Resource Recovery and Upcycling

Resource recovery includes extracting usable materials or energy from waste. Upcycling goes a step further by converting waste into products of higher value. For instance, fly ash from coal combustion can be used as a pozzolanic material in concrete production, improving mechanical strength and reducing cement consumption.

Emerging technologies in waste-to-energy (WtE) and waste-to-material (WtM) offer industrial players avenues to recover value from waste. For example, chemical recycling processes are being developed to break down multi-layered plastics into monomers that can be repolymerized into virgin-quality plastic (Anuar et al., 2025).

5. Digital Technologies and Integrated Management Strategies

The advent of digitalization has fundamentally transformed waste management practices, revolutionizing how industrial waste streams are monitored, optimized, and regulated across the entire value chain. Technologies such as artificial intelligence (AI), machine learning (ML), geographic information systems (GIS), and the Industrial Internet of Things (IIoT) form the backbone of this evolution, enabling unprecedented real-time tracking of waste generation, composition, and flows through sensor-equipped smart bins, conveyor systems, and networked facilities. These tools facilitate advanced data analytics for identifying inefficiencies—such as suboptimal sorting or overfilled storage—and predictive decision-making that forecasts waste volumes, optimizes collection routes, and preempts compliance risks with dynamic adjustments to process parameters (Olawade et al., 2024). By integrating platforms like digital twins for virtual simulation of waste treatment scenarios and blockchain for traceability, digital solutions not only enhance operational efficiency and cost savings but also support regulatory reporting and stakeholder transparency in line with EU circular economy directives.

5.1. Smart Waste Monitoring and Analytics

Smart bins equipped with IIoT sensors can report fill levels, contamination, and temperature, allowing for optimized waste collection routes and reduced fuel consumption. In industrial settings, real-time monitoring systems ensure compliance with emission limits and enable traceability across waste supply chains.

Big data analytics allow organizations to identify trends in waste generation, assess process performance, and detect anomalies. Machine learning models have been deployed to optimize sorting systems and to predict the economic viability of recycling specific waste streams (Kannan et al., 2024).

5.2. Integrated Waste Management Systems

Integrated waste management (IWM) refers to the coordinated use of multiple waste treatment and disposal methods to manage waste effectively. It involves waste minimization at the source, followed by segregation, recovery, treatment, and final disposal. A robust IWM strategy combines:

- Policy instruments (e.g., landfill taxes, recycling mandates),
- Technological solutions (e.g., automated sorting, pyrolysis),
- Social interventions (e.g., employee training, corporate responsibility).

International standards such as ISO 14001 (Environmental Management Systems) provide a framework for implementing systematic and accountable waste management practices in industrial organizations (Seadon, 2006).

6. Discussion

The reviewed literature provides a robust foundation for industrial waste management strategies, yet reveals critical limitations in practical implementation. Preventive approaches such as process optimization and eco-design perform well in controlled or laboratory settings (Singhal et al., 2024; Alsabt et al., 2024), but rarely address sector-specific barriers in Poland's heavy industry—high capital costs, legacy infrastructure, and complex inherited environmental regulations from the transformation period.

Waste processing methods (physical, chemical, thermal, biological) demonstrate material and energy recovery potential (Alao et al., 2022; Pilarska et al., 2023; Ragaert et al., 2017), but studies overlook long-term cost-effectiveness analyses and environmental trade-offs (e.g., energy-intensive pyrolysis emissions). Circular economy models, including industrial symbiosis (Valentine, 2016), succeed in showcase projects like Kalundborg but face scalability issues, governance gaps in inter-firm networks, and dependency on partner trust (Naqvi et al., 2021).

Industry 4.0 technologies (IIoT, AI/ML, digital twins) enable real-time prediction and optimization (Kannan et al., 2024; Olawade et al., 2024), yet neglect digital transformation challenges: data silos in legacy systems, cybersecurity risks, and skills shortages in industrial regions (Horzela-Miś, Semrau, 2025).

Novel contributions of this review include systematic synthesis of prevention-processing-digitalization strategies contextualized for Polish heavy industry, identification of mining and metallurgy-specific barriers (competency deficits, data infrastructure gaps), and a prioritized research agenda: hybrid digital-preventive models compliant with EU Green Deal.

Lessons learned emphasize a sequential approach: source prevention first, then valorization with value recovery, supported by digitalization. Significance for the field impacts public policy (national zero-waste strategies), corporate management (symbiosis pilot roadmaps), and academia (LCA-symbiotic methodological frameworks).

Practical applications include waste valorization audit tools and cross-sector collaboration networks, accelerating circular transformation in Central European resource economies.

Implementation recommendations:

- Short-term: Deploy IIoT for waste stream monitoring.
- Medium-term: Pilot industrial symbiosis in Silesian economic zones.
- Long-term: LCA-based decision systems for corporate strategies.

7. Conclusion

This literature review confirms that an integrated approach to industrial waste management—combining source prevention (UNEP, 2007; Singhal et al., 2024), advanced valorization technologies (Alao et al., 2022; Pilarska et al., 2023), circular economy principles (Naqvi et al., 2021; Valentine, 2016), and Industry 4.0 digital transformation (Kannan et al., 2024; Olawade et al., 2024)—represents the most promising pathway for developing sustainable waste management systems.

As detailed in the Discussion section, the critical evaluation of the literature identifies key implementation barriers in Poland's heavy industry: competency deficits, data infrastructure gaps, and digital transformation challenges in legacy sectors (Horzela-Miś, Semrau, 2025; Semrau, 2025). Nevertheless, these identified research limitations create a concrete agenda for future work: quantitative LCA assessments, industrial symbiosis network modeling, and the development of decision-support tools adapted to EU Green Deal regulations.

The main theses of this paper encompass a sequential action hierarchy—prevention, valorization, digitalization—as the optimal transformation model for Polish mining and metallurgy contexts. The article's contribution lies in contextualizing international solutions for Central Europe and providing practical recommendations for public policy (zero waste strategies), business (industrial symbiosis pilots), and science (LCA-symbiotic methodological frameworks).

Implementing the proposed solutions according to short-term (IIoT monitoring), medium-term (symbiosis in Silesian economic zones), and long-term (LCA decision systems) sequences will accelerate the transition from linear to circular industrial models. This will enhance Poland's competitiveness within EU climate goals and environmental regulations, bridging the gap between theory and practice in Industry 4.0 transformation.

The paper provides managers, policymakers, and researchers with a ready strategic framework for operationalizing sustainable waste management under regulatory and technological constraints.

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CONSTRUCTION LAST MILE DELIVERIES AND URBAN QUALITY OF LIFE

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Purpose: The purpose of this paper is to assess the extent to which last-mile deliveries associated with the implementation of construction projects—covering infrastructure developments, residential buildings, and non-residential structures—affect the quality of life of residents in urban areas.

Design/methodology/approach: The paper adopts an analytical approach grounded in construction logistics and supply chain management theory. It examines the specific characteristics of construction as a project-based industry and their implications for supply chain configuration, with particular emphasis on last-mile delivery processes in urban construction projects. Data related to different types of construction investments and delivery practices are analyzed to identify their influence on urban residents' quality of life.

Findings: The analysis indicates that last-mile deliveries in urban construction projects constitute a significant source of negative externalities affecting residents' quality of life, including disturbances related to traffic congestion, noise, and accessibility. The magnitude of these impacts varies depending on the type of construction project, the project delivery system, and the organization of the construction supply chain.

Research limitations/implications: The study is limited by its reliance on survey-based perceptions of residents, which may be influenced by individual sensitivity and proximity to construction sites. The analysis does not include quantitative measures of last-mile delivery intensity or long-term post-construction effects. Future research should incorporate objective traffic, noise, and emission data, longitudinal analyses, and comparative studies across different urban contexts, particularly in relation to sustainable urban planning and transport systems.

Practical implications: The findings indicate the need for improved planning and management of last-mile deliveries to urban construction sites, particularly to mitigate mobility disruptions, congestion, noise, and air pollution. Construction firms should optimize delivery schedules and logistics organization, while local authorities should integrate construction logistics into urban transport planning, especially for civil engineering projects with higher perceived impacts.

Social implications: The findings demonstrate that construction-related last-mile deliveries affect residents' mobility, daily functioning, and environmental comfort in urban areas. The study supports the need for socially responsible construction logistics and may inform public policies aimed at improving urban livability and quality of life.

Originality/value: The paper provides original empirical evidence on the impact of construction-related last-mile deliveries on urban residents' quality of life.

Keywords: construction logistics; last mile delivery; urban quality of life; urban construction projects; supply chain.

Category of the paper: Research paper.

1. Introduction

Construction plays a crucial role in the development of urban spaces. The implementation of construction projects enables the satisfaction of the needs of an increasingly large population of residents, both in the context of residential and service provisions, as well as through access to products and infrastructure. Consequently, this industry has a significant impact on quality of life in cities. The products resulting from construction activities largely bring positive outcomes to communities; however, the processes necessary for their creation may exert negative effects on various aspects of the functioning of urban agglomerations. Particular attention should be devoted to processes related to the functioning of construction supply chains.

Construction Supply Chains (CSC) have a specific nature and consist of investors, designers, contractors, and suppliers (Vrijhoef, Koskela, 2000). Due to the project-based character of the activity, CSCs are characterized by low durability, fragmentation, and continuous reconfiguration. Typically, individual links participate in more than one supply chain, and the chain itself is typical to production make-to-order (Vrijhoef, Koskela, 2005). The links do not exist within a customer-directed flow; consequently, different flows do not occur in a standardized manner. The configuration of the supply chain is significantly determined by the selected system of construction project implementation, the procurement system, the type of final client (public or private entity), and the type of project being executed. Additionally, CSCs possess different levels: basic (materials), auxiliary (equipment), and human (labor force) (Al-Werikat, 2017). Flows at different levels may occur in opposite directions. A further complication is the substantial influence of the client on the final project in both logistical and physical aspects, the transactional nature of relations between the buyer and the supplier, the number of involved stakeholders, the short planning horizon, resistance to change, and the cyclical nature of demand (Behera, Mohanty, Prakash, 2015). These characteristics determine a specific approach to supply chain management in construction (CSCM) (Papadopoulos, Zamer, Gayialis, Tatsiopoulou, 2016).

Last-mile deliveries represent the most costly and least efficient segment of the supply chain. Furthermore, they are considerably less sustainable (Yılmaz, Aktaş, Demirel, 2022). In the construction industry, they constitute an even greater challenge for SCM due to the nature of the cargo being transported, the participants in the supply chain, and the manner of organization of construction processes. The impact they exert on the urban environment can be considered exceptionally significant and negative (Osypchuk, Iwan, 2019). Consequently, they may also influence quality of life in cities. A review of the relevant literature indicates insufficient exploration of the subject. Publications in this field predominantly focus on sustainable construction and sustainable construction supply chains, with particular emphasis on environmental and economic aspects (Karlsson et al., 2020; Ogunmakinde, Egbelakin, Sher, 2022; Tabassum, Mir, 2023; Zhang, 2024). The neglect of social sustainability aspects indicates the presence of a research gap.

The aim of this article is to assess to what extent last-mile deliveries associated with the implementation of construction projects—encompassing infrastructure, residential, and non-residential facilities—affect the quality of life of residents. The collected data may serve as a foundation for developing recommendations for local authorities and construction firms to mitigate the identified negative impacts in the examined area.

In Section 2, the authors present the specific characteristics of last-mile deliveries in the construction industry and their impact on quality of life in cities. In Section 3, the authors present the research methodology, Section 4 discusses the research findings, whereas Section 5 presents the conclusions.

2. Last Mile Deliveries in construction in reference to quality of life in cities

Last-mile deliveries constitute a frequently addressed issue, particularly within the context of their environmental impacts. Urban freight deliveries are characterized by the involvement of multiple stakeholders, short transportation routes, reduced vehicle speeds, limited effective driving time, constrained spatial capacity, insufficient traffic infrastructure coupled with elevated transportation demand and operational inefficiency. Furthermore, urban freight transport is contingent upon local infrastructural conditions and limitations (such as designated unloading zones) as well as emerging trends, including increasing demand for service provisions (Bosona, 2020). The construction industry, in this context, additionally confronts the necessity of utilizing heavy-tonnage transportation, absence of delivery optimization, fragmentation, partial cargo loading, and exceptionally elevated empty-return trip rates (Zhang, 2024). Consequently, last-mile deliveries in construction represent a significant challenge for urban areas, considering their impacts on air pollution, noise emissions, safety levels, traffic

congestion phenomena, and infrastructural conditions (Giuliano, 2023). The intensification of these challenges naturally contributes to a deterioration in residents' quality of life.

Quality of life (QoL) is defined heterogeneously depending on the utilization context. It is assessed through multiple parameters spanning the dimensions of health, education, natural environment, infrastructure (social, residential, and municipal), economic well-being, safety, labor market conditions, personal fulfillment, individual freedom, and social relationships (Sapena, 2021). Increasingly, scholarly attention has been directed toward urban quality of life as an element affecting overall QoL. For the purposes of this article, specific parameters of urban quality of life have been identified, which may be susceptible to impact from last-mile construction deliveries, as illustrated in Figure 1.

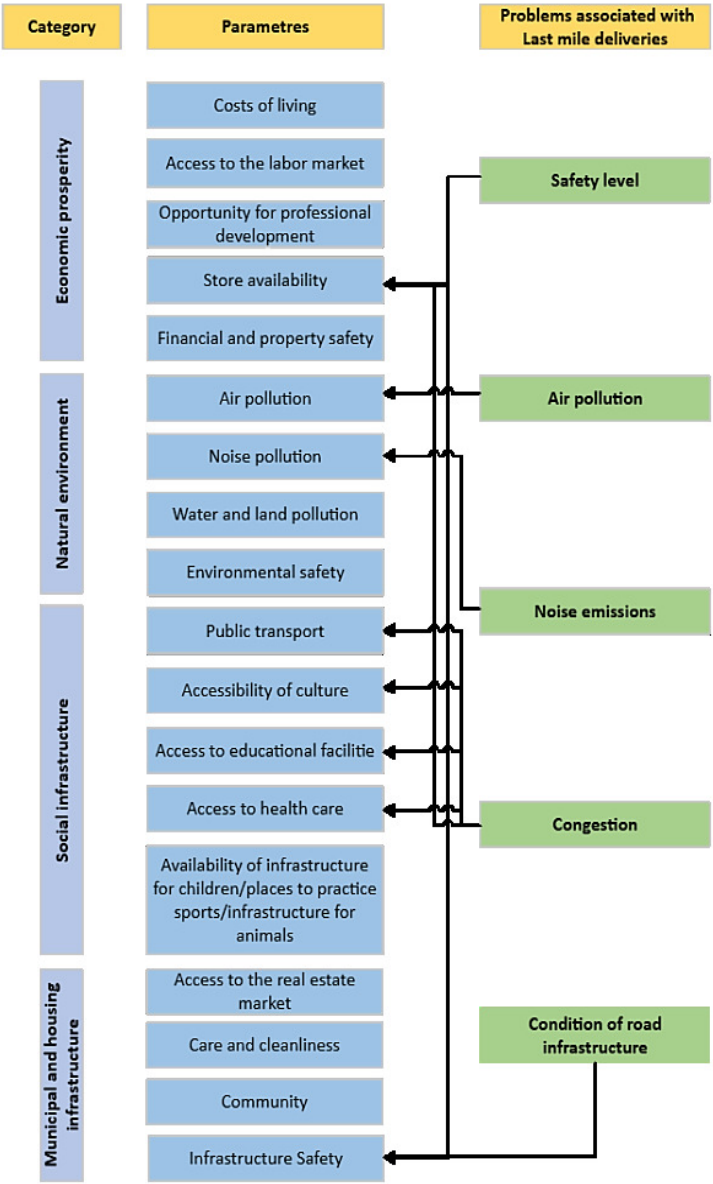


Figure 1. Selected Urban Quality of Life (UQoL) Parameters That May Be Influenced by Last-Mile Delivery Operations.

Source: own study.

The elevation of transport volume associated with construction material supply contributes to an intensification of congestion phenomena, which in turn may exert significant impacts on economic well-being (store availability) as well as on elements of social infrastructure (public transportation, cultural facility accessibility, educational institutions, and medical facilities). This occurs both through the extension of travel duration and the unavailability of parking capacity in connection with loading and unloading operations. Additionally, freight transport creates heightened accident hazards (McDonald, Yuan, Naumann, 2019), thereby affecting infrastructure safety, constitutes a significant source of noise emissions and air pollution, and may adversely impact infrastructural conditions.

3. Research Methodology

The adopted research process involved a comprehensive literature review, during which the authors identified a research gap regarding the assessment of the impact of last-mile delivery in construction project implementation on residents' quality of life. The research subjects encompassed construction projects related to the development of infrastructure facilities as well as residential and non-residential buildings.

The research process was structured in several phases. The first phase consisted of expert consultations conducted to identify the elements comprising quality of life in urban areas. The subsequent step involved the development of a standardized questionnaire based on current scientific knowledge in the field of construction investments' impact on quality of life. To ensure questionnaire validity and eliminate potential errors, preliminary research was conducted on a targeted sample comprising five researchers employed in scientific research institutions. This phase lasted from December 2022 to February 2023. The refined questionnaire enabled the execution of survey research. The questionnaire consisted of two components: demographic questions section and substantive section. Data collection was conducted using the snowball sampling method, which involved distributing the questionnaire online to successive participants. To increase response rates, the authors also conducted offline surveys. All collected data from both online and offline questionnaires were integrated into a single database. This phase lasted five months, from March to July 2023.

The geographic scope of the research was the city of Szczecin, the capital of the West Pomeranian Voivodeship, located in the northwestern region of Poland. Due to its strategic location, this city holds important administrative, economic, and transportation roles in the country (Office of the Association of the Szczecin Metropolitan Area, 2025).

Quantitative research participants included residents of Szczecin of working age. The sample size was calculated based on 2022 data, when the working-age population of Szczecin was 227,971 individuals. The calculations were based on the following assumptions:

the fraction size was determined at 0.5, the confidence level was set at $\alpha = 0.85$, and the measurement error was established at 5%. During the implementation of the research process, $n = 210$ completed questionnaires were collected. This indicates that the sample selection is appropriate and representative for the research area.

Formal consent from respondents was not necessary for the utilization and publication of survey data, as the survey was conducted anonymously.

4. Survey results

A quantitative study encompassing 210 respondents was conducted. The initial section of the survey instrument consisted of demographic questions. With respect to gender composition, the research sample comprised 124 female participants (59.05%) and 86 male participants (40.95%). Analysis of participant age distribution revealed the following distribution: 174 individuals (82.86%) fell within the 18-25 years age bracket, 24 individuals (11.43%) were aged 26-35 years, and 6 individuals each (2.86% respectively) belonged to the 36-45 years and 46-59 years age groups. Regarding educational attainment: 58 respondents (27.62%) possessed higher education credentials, while 152 individuals (72.38%) had completed secondary education.

The second section of the survey questionnaire comprised targeted research questions. The initial query was formulated as follows: "Is there a construction site for residential or non-residential buildings in the vicinity of your place of residence or employment?" In response, 122 respondents (58.10%) provided affirmative responses, whereas 88 individuals (41.90%) indicated negative responses, signifying the absence of construction sites in their residential and/or employment vicinity. The obtained findings demonstrate a considerable degree of exposure of local communities to construction activities. This query was subsequently posed to respondents in the context of projects associated with civil engineering structures, formulated as: "Is the construction, reconstruction, or renovation of civil engineering structures (all construction objects not classified as buildings) occurring in the vicinity of your place of residence or employment?" Affirmative responses were provided by 110 individuals (52.4%), while 100 individuals (27.6%) furnished negative responses. The fact that more than half of the respondent population declares the presence of construction sites within their immediate surroundings constitutes a substantial justification for the continuation and deepening of research investigations in this domain.

In the subsequent survey questionnaire item, respondents were requested to evaluate the impact of ongoing construction projects on their daily functioning, with the query formulated as: "Do you perceive the impact of ongoing construction projects on your daily functioning?" Respondent replies were distributed as follows: 23 individuals (11.0%) indicated that they

experienced very significant impacts, 38 individuals (18.1%) reported substantial impacts, 70 individuals (33.3%) identified moderate impacts, 20 individuals (9.5%) reported minimal impacts, and 59 individuals (28.1%) declared that they did not perceive any impacts from the ongoing construction investments.

The responses to this query permit the article authors to conclude that a decisive majority of respondents (72%) declares perceptible impacts of construction investments and accompanying material deliveries on their daily existence—varying in intensity levels. Fewer than one-third of the surveyed population (28%) reported no significant alterations in their daily functioning related to the material deliveries and construction projects being undertaken. These findings substantiate the appropriateness of further exploration of this phenomenon, particularly within the context of residents' quality of life.

In the two subsequent multiple-choice questions, respondents were requested to identify which of the enumerated elements were affected by construction investments and their accompanying material deliveries (Fig. 2). The initial query concerned residential and non-residential building projects. The most frequently identified area of impact was noise level—this element was selected by 145 respondents. Subsequent responses included, respectively: traffic congestion (100 responses), delays in transportation services (passenger and public transportation) (97 responses), and mobility (86 responses). The least frequently selected responses were: transportation costs (23 individuals) and operation of enterprises, services, or shops (34 individuals). In the query addressing civil engineering projects, respondents identified elements such as: traffic congestion (143 individuals), noise level (120 individuals), mobility (111 individuals), delays in transportation (109 individuals), and difficulties in route planning (102 individuals). The least frequently selected responses were: transportation costs (27 individuals) and operation of enterprises, services, or shops (35 individuals).

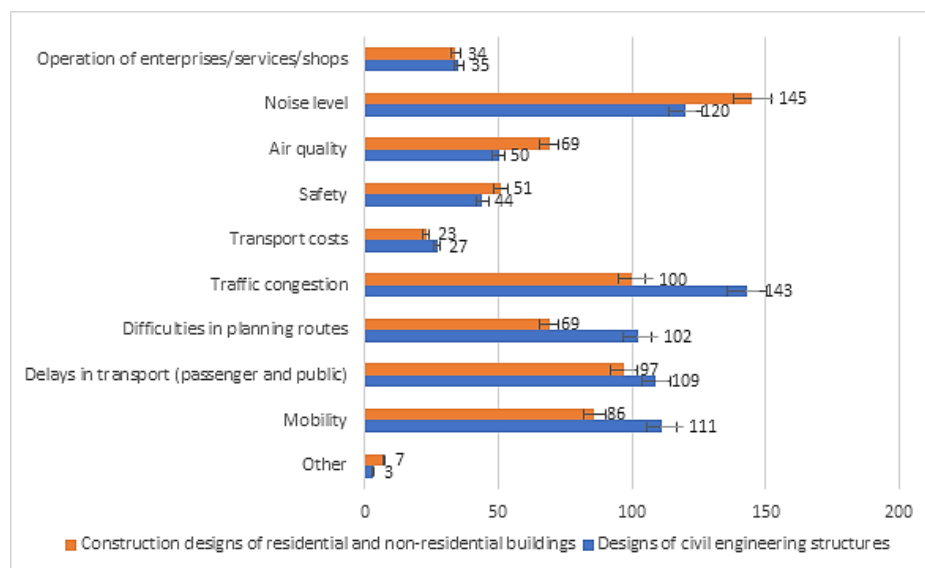


Figure 2. Impact of construction investments and last-mile material deliveries on selected elements – respondents' assessment.

Source: own study.

The findings unequivocally indicate that the greatest burdens associated with the implementation of construction projects—encompassing both residential and non-residential buildings, as well as civil engineering infrastructure—as perceived by residents concentrate around aspects such as noise pollution and transportation-related factors (congestion and mobility). These impacts may be directly correlated with the intensification of construction activities, the necessity of executing last-mile construction material deliveries, as well as the unloading and temporary storage of construction materials. Comparatively diminished significance was attributed to the impact of ongoing construction investments on local commercial and retail operations, as well as transportation expenses.

Subsequent research questions were structured and administered in reference to the examined dimensions of quality of life. Respondents were asked to evaluate the impact of construction projects associated with residential buildings, non-residential structures, and civil engineering infrastructure on quality of life aspects related to economic prosperity, specifically regarding retail accessibility (Figure 3). The majority of respondents indicated a substantial impact at 30% and a moderate impact at 24%. Approximately 20% of surveyed participants identified no impact on retail accessibility. In the case of civil engineering projects, responses similarly demonstrated a predominance of substantial impact at 31% and moderate impact at 27%, whereas 23% of respondents assessed the impact as minimal.

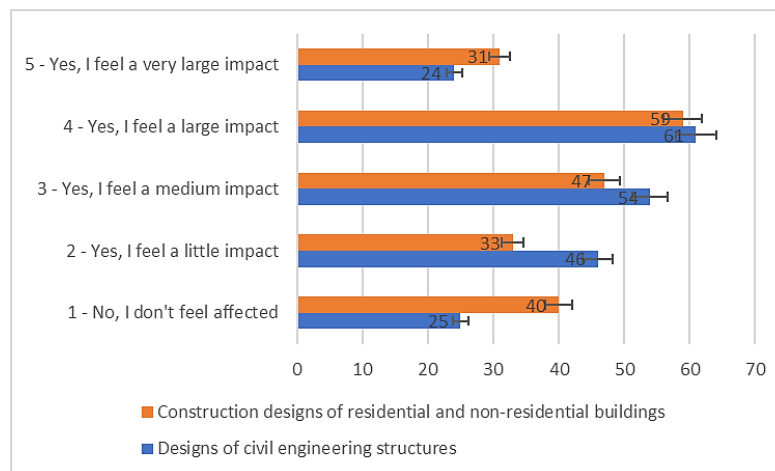


Figure 3. Assessment of the Impact of Construction Project Implementation and Associated Last-Mile Delivery Operations on Individual Aspects of the Economic Prosperity Dimension: Store Availability.

Source: own study.

The subsequent examined dimension was the natural environment (Figure 4). Considering last-mile delivery operations associated with the implementation of residential and non-residential building projects, the largest respondent cohort indicated a moderate impact of 34% and substantial impact of 22% on air pollution levels (Figure 4a). For civil engineering projects, responses were predominantly characterized by very substantial impact at 27%, moderate impact at 26%, and substantial impact at 25%. Analyzing the impact of residential and non-residential building project implementation on noise pollution (Figure 4b), responses were predominantly categorized as very substantial at 39% and substantial at 23%. In civil

engineering project implementation, responses similarly predominated, with very substantial impact at 41% and substantial impact at 27%. The analyzed data demonstrate that respondents perceive construction project implementation as significantly affecting the natural environment dimension, particularly in the context of noise emissions and air pollution. During the execution of construction investments, air pollution may be attributable to both delivery operations and the implementation of specific construction activities (such as demolition, drilling, and material cutting), which may generate particulates and other contaminants. Noise accompanying construction investments may result not only from transportation operations but also from a broad spectrum of contributing factors, including, among others, pile driving for building foundations, aforementioned demolition activities, and noise emissions from construction equipment and vehicles.

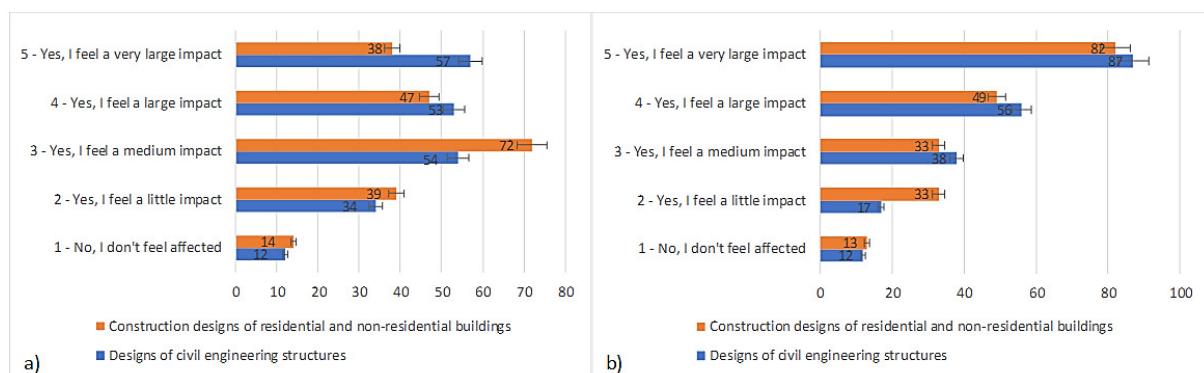


Figure 4. Assessment of the Impact of Construction Project Implementation on Individual Aspects of the Natural Environment Dimension: a) Air Pollution; b) Noise Pollution.

Source: own study.

In the subsequent analytical section, the social infrastructure dimension was evaluated (Figure 5). Regarding the implementation of residential and non-residential building projects, respondents most frequently indicated a moderate impact of 27% and minimal impact of 21% on public transportation accessibility and functionality (Figure 5a). For civil engineering projects, responses were predominantly characterized by very substantial impact at 52%, with substantial impact constituting the second most prevalent category at 23%. The implementation of residential and non-residential building projects in the context of cultural accessibility (Figure 5b) was primarily assessed as exhibiting no impact at 28%, moderate impact at 27%, or minimal impact at 26%. In civil engineering projects, respondents most frequently indicated moderate impact at 30%, minimal impact at 23%, and substantial impact at 22%. Regarding accessibility to educational facilities (Figure 5c), during the implementation of residential and non-residential building projects, responses predominantly reflected minimal impact at 25% and moderate impact at 24%; conversely, during civil engineering project implementation, respondents similarly indicated primarily moderate impact at 30% and substantial impact at 26%. In the context of healthcare accessibility (Figure 5d), for building projects, responses were distributed equally across three categories: no impact at 25%, moderate impact at 25%,

and minimal impact at 25%. When evaluating civil engineering project implementation, respondents characterized the impact as moderate at 30%, substantial at 24%, and minimal at 23%. Based on the compiled empirical data, it can be concluded that the implementation of construction projects—encompassing both residential and non-residential buildings as well as civil engineering projects—demonstrates moderate impact on urban quality of life in the social infrastructure dimension across most cases. The most substantial effects were observed in the public transportation sector, particularly for civil engineering projects. Based on the obtained results, it is noteworthy that construction site location may necessitate modifications to urban transportation operations, particularly in the case of infrastructure investments. Furthermore, as a consequence of last-mile delivery operations in construction and material unloading activities, congestion phenomena may emerge, which consequently may substantially affect the functionality of urban transportation systems.

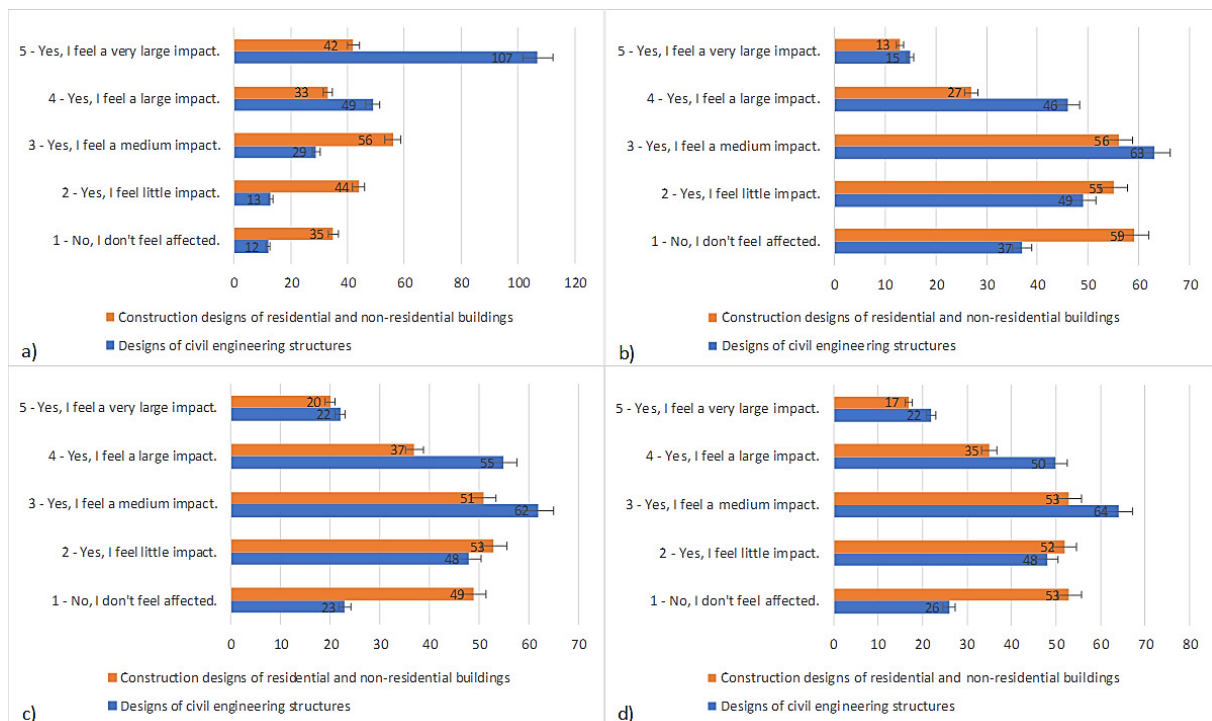


Figure 5. Assessment of the Impact of Last-Mile Delivery Operations Associated with Construction Project Implementation on Individual Aspects of the Social Infrastructure Dimension: a) Public Transportation; b) Cultural Accessibility; c) Access to Educational Facilities; d) Access to Healthcare Services.

Source: own study.

The subsequent quality of life dimension subjected to analysis was municipal and housing infrastructure in the context of infrastructure safety (Figure 6). In the first examined domain, encompassing residential and non-residential building projects, respondents assessed the impact as follows: moderate impact at 30% of respondents, very substantial impact at 20% of respondents, and substantial impact at 20% of respondents. Regarding civil engineering project implementation, respondents characterized the assessed impact as: moderate impact at 28% of respondents, minimal impact at 20% of respondents, substantial impact at 19% of respondents,

and very substantial impact at 19% of respondents. Based on the obtained empirical data, it can be inferred that the execution of delivery operations to construction sites is perceived as an element of moderate influence on the sense of safety within urban space. Both project types were evaluated comparably by respondents in this analytical dimension.

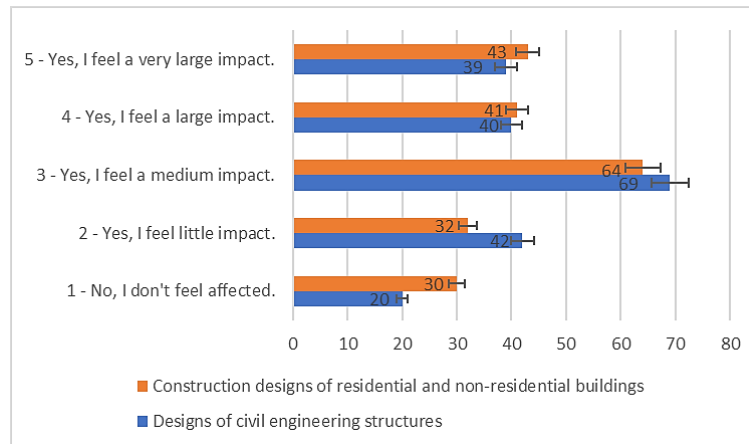


Figure 6. Assessment of the Impact of Construction Project Implementation on Infrastructure Safety.

Source: own study.

The conducted research affirms that the majority of respondents are directly exposed to the impacts of delivery transportation associated with the implementation of construction projects in urban environments, encompassing both residential and non-residential buildings as well as civil engineering infrastructure. More than half of the study participants identified the presence of construction sites within their immediate surroundings, which translates into a substantial proportion of individuals perceiving the effects of ongoing construction investments and last-mile delivery operations on their daily functioning. Across the examined quality of life dimension, construction projects demonstrate heterogeneous yet predominantly moderate impacts. Respondents observed the most substantial effects in domains pertaining to noise emissions, air pollution, urban transportation systems, and residential mobility. The empirical research findings indicate that the degree of impact from construction project implementation and associated last-mile delivery operations depends upon both the type of construction investment on which last-mile delivery operations are executed and the specific operational characteristics of the given investment.

5. Discussion and Conclusions

Analysis of the obtained survey results indicates that the implementation of construction projects, both residential and non-residential, as well as civil engineering projects, does impacts the examined quality of life based on assumed measurements mentioned in this article. When considering the social infrastructure dimension, changes in public transport were most

noticeable in civil engineering projects, they were perceived with significantly greater impact (75% of responses indicating a significant or very significant impact), while residential and non-residential projects generated mainly a medium or small impact. In other areas – such as access to culture, education, and healthcare – responses were indicating none or moderate impact. This suggests that the overall toll and disruptions associated with construction projects are more localized, primarily affecting public spaces and residents' mobility. These results are consistent with the literature, which indicates that the impact of construction investments is primarily concentrated in areas of mobility (Harleman, 2023).

In the economic prosperity dimension, respondents most frequently indicated that construction projects have a noticeable impact on the accessibility of shops, most often to a large or moderate extent. This means that investments of all types – both residential and non-residential buildings, as well as civil engineering infrastructure – are perceived as disrupting to residents' daily routines.

In the natural environment dimension, the impact of construction projects in terms of noise and air pollution was assessed as significant. Civil engineering projects were assessed as having a greater impact than residential and non-residential buildings. Literature indicates that factors such as last-mile transport intensity, project duration, and investment scale are key drivers of environmental impacts during the construction phase (Zou, Ergan, 2018; Ballesteros, 2010).

An assessment of the municipal and housing infrastructure dimension in the context of infrastructure safety indicated that the impact of last-mile deliveries is perceived as moderate by residents, and the responses provided by respondents were similar for both types of projects. Based on this, it can be concluded that, that type of investment does not significantly differentiate the perceived level of safety in urban spaces.

The data obtained from the research process indicates that the implementation of construction projects affects local communities daily. More than half of the surveyed participants confirmed that there was a construction site in their immediate vicinity, both for residential and non-residential buildings, as well as for civil engineering projects. Because 72% of surveyed people indicated that ongoing construction projects (to varying degrees) their daily functioning makes this to be a significant point. By referring to the multidimensional understanding of quality of life presented in the literature (Sapena, 2021), the results indicate that last-mile construction deliveries influence several interconnected dimensions of urban quality of life, particularly mobility, environmental conditions, and economic accessibility. This confirms that construction logistics should be considered not only as an operational issue, but also as a socially relevant urban challenge. Considering the results, continued research in this area is crucial, especially in the context of sustainable urban planning and urban transport. Last-mile deliveries to construction sites are impacting the functionality of transportation systems, which then is reflected in congestions in the transportation network, mobility of local communities, traffic flow, and travel comfort, while also increasing noise and pollution emissions.

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EXPLORING IMMERSION IN VIRTUAL REALITY: OVERVIEW AND RESEARCH PERSPECTIVE

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Purpose: The aim of this article is to review the definition and understanding of the immersion phenomenon in virtual reality (VR) and identify research gaps related to the definition, understanding, and measurement of immersion. The paper also aims to demonstrate, initially, that immersion is a real-world phenomenon, empirically observable in various VR contexts and intuitively evaluated by users.

Design/methodology/approach: The first part of the article is a review, as the author has conducted an overview of the definition and understanding of immersion phenomenon. Furthermore, the author presents the initial results of her own research based on surveys. Based on the review and surveys, the author identifies a research gap and formulates research questions that will serve as a starting point for practical research.

Findings: The results of the literature review show that immersion is defined differently across disciplines, and various factors that may influence it are identified. There is a lack of research on the factors that influence immersion and how to measure immersion levels. There is also a lack of comprehensive practical research on immersion with users. The paper identifies the research gap and formulates research questions based on the literature review and initial surveys.

Research limitations/implications: This article is exploratory in nature and concerns the phenomenon of immersion in virtual reality. It presents the first stage of research, namely literature research. It is therefore an introduction to the discussion on defining and understanding immersion, as well as an introduction to practical research.

Practical implications: The article identifies a research gap based on a literature review and the authors' preliminary studies. Furthermore, the article formulates research questions that will be addressed in subsequent studies.

Originality/value: This article adds value by combining a literature review with empirical results from authors' own research conducted in various VR contexts. The article identifies a research gap and research questions, which serves as a starting point for further practical research on immersion in virtual reality.

Keywords: virtual reality, immersion, immersive, VR goggles, immersive technologies, VR.

Category of the paper: Research paper.

1. Introduction

Key developments in immersive technologies, like virtual reality (VR), have changed them into widely accessible tools for entertainment and professional use over recent years. They are not only of interest to users for entertainment purposes, such as interactive and experimental games and activities but VR can be used also in education, industry, medicine, tourism, sports and many different fields. One of the key characteristic features of VR is phenomenon called immersion. Thus, VR users can immerse themselves in a different reality, experience a strong sense of presence in a three-dimensional virtual world, and forget themselves. It often leads to a loss of sense of real space and time. Users just need to put on VR goggles. As experience progresses, a user becomes increasingly deeply involved with the created environment. Virtual reality allows users to engage not only the mind but also the body. VR users can have different interactions. They usually use controllers but in the case of the latest technologies, there is even no need for controllers anymore – technology enables tracking of hand movements. VR users can lift, throw and touch virtual objects. At a certain stage, they lose awareness of the physical environment they are actually in. Because they see the unreal 3D world around them and cannot see the real space, their perception is entirely filled with a virtual environment. Then a strong sense of "being somewhere else" emerges. This is the essence of immersion.

This article addresses the topic of immersion in virtual reality. The first part of the article is a review, as the author has conducted an overview of the definition and understanding of immersion phenomenon. Furthermore, the author presents the initial results of her own research based on surveys. Based on the review and surveys, the author identifies a research gap and formulates research questions that will serve as a starting point for practical research. This article, therefore, serves as a starting point for further research and opens a discussion on defining and measuring immersion in virtual reality.

2. Review of Immersion in Virtual Reality

This chapter reviews the definition of the concept of immersion in virtual reality. The research was based on literature searches conducted in Scopus and Google Scholar. References were made to literature that presented the definition and understanding of immersion from various perspectives. The author refers not only to theoretical definitions and descriptions of immersion but also to the results of practical (experimental) research. The chapter is divided into two subchapters. The first sub-chapter presents the mentioned definitions and general concept of immersion in VR. The second sub-chapter presents the conclusions drawn from the conducted review.

2.1. An Overview of Definitions

The concept of immersion is metaphorical and originates from the bodily experience of physical immersion, for example, in water (Murray, 2017). It refers to the subjective feeling of being in a radically different environment – similar to the difference between air and water. In such a state, the individual feels fully surrounded by a new reality that dominates their attention and perception.

In the literature, the concept of immersion appears in numerous research contexts and is used across various scientific disciplines. It applies to both technical sciences, where it is analyzed in the context of designing interactive systems, virtual environments, and user interfaces, and to the social sciences, where it is considered in relation to communication, digital media, and user experience. The concept also holds a significant place in psychology and cognitive sciences, where immersion is described as a state of cognitive, emotional, and perceptual engagement. Furthermore, the term also appears in research in education, art, computer games, and even therapy, demonstrating its interdisciplinary nature. Various definitions and perspectives on immersion are discussed below.

In the context of psychological experiences, immersion is described as a state of deep cognitive engagement in which mental processes – regardless of the intensity of sensory input – lead to a significant shift in attentional focus. This results in a partial or complete detachment from awareness of the physical world and a focus on the experienced alternative reality (Agrawal et al., 2019). In other words, immersion is a state of concentration and cognitive engagement that depends on the ability to control attention and minimize distractions (Witmer, Singer, 1998). It is worth noting that this approach does not address emotional or physiological aspects.

Research on emotion analysis in virtual reality environments indicates that eliciting emotional responses in users promotes increased attention and engagement in the VR experience (Baños et al., 2004). Further analyses also demonstrated a relationship between social emotions and the experience of immersion. According to Bailenson and Yee's (Bailenson, Yee, 2008) research, social interactions and collaboration with other participants in the virtual environment lead to intensified emotional engagement, which indirectly translates into a deeper sense of immersion. Weibel et al. (Weibel et al., 2010) emphasize the role of individual emotional predispositions, suggesting that the level of immersion may be related to specific personality traits, such as neuroticism or openness to new experiences. Users characterized by greater emotional sensitivity are more likely to achieve a high level of immersion in the virtual environment. At the same time, the authors emphasize that some existing research focuses primarily on psychological factors, omitting the technical and visual aspects of VR applications, such as the quality of object representation, haptic stimuli, and system technological parameters.

In the literature on immersion in virtual reality, a significant portion of research focuses on its technical dimension. The authors of these studies analyze immersion primarily in relation to VR system parameters, such as graphic quality, sound realism, and user tracking precision (Bowman et al., 2012; Cummings, Bailenson, 2016; Kwon et al., 2016; Slater, Wilbur, 1997). In such approaches, the emphasis is primarily on the hardware and visual aspects of virtual environments, with less consideration given to users' subjective experiences, including their emotional reactions and level of psychological engagement. Cummings and Bailenson (Cummings, Bailenson, 2016) even gives the term of “technological immersion”. According to their research, increased levels of user-tracking, the use of stereoscopic visuals, and wider fields of view of visual displays are significantly more impactful on user experience of presence than improvements to most other immersive system features, including quality of visual and auditory content. Slater and Wilbur (Slater, Wilbur, 1997) propose that the degree of immersion can be objectively assessed as the characteristics of a technology. Immersion also has different dimensions: the extent to which a display system can deliver an inclusive, extensive, surrounding and vivid illusion of virtual environment to a participant; the extent of body matching; the extent to which there is a self-contained plot in which the participant can act and in which there is an autonomous response.

The literature also includes interdisciplinary studies that attempt to comprehensively address the phenomenon of immersion. These studies often combine technological, psychological, and cognitive perspectives, but in many cases, they are limited to theoretical considerations or laboratory experiments, without the participation of actual users in natural VR environments (IJsselsteijn et al., 2000; McMahan, 2013; Slater, 2003). Despite the fact that a meta-analysis conducted by Cummings and Bailenson (Cummings, Bailenson, 2016) demonstrate that a high level of technological immersion promotes a stronger subjective sense of presence in a virtual environment, but the impact of individual factors remains ambiguous and poorly organized. Therefore, a coherent, integrated model that combines the various determinants of the immersion experience, such as technological, design, emotional aspects, and individual user characteristics, is still lacking. The literature emphasizes that measuring immersion levels and the sense of presence in a virtual world is a complex issue.

There are also conclusions suggesting a lack of practical experiments on this topic (Degenhard et al., 2025; McGowin, Fiore, 2024; Zhang et al., 2025). As McGowin and Fiore (McGowin and Fiore, 2024) point out, quantifying immersion poses a significant research challenge, primarily due to the lack of standardized and systematic measures relating to the technical capabilities of virtual reality systems. The authors note that existing measurement approaches often do not allow for a clear and comparable assessment of the level of immersion across different VR solutions. Degenhard et al. (Degenhard et al., 2025) emphasize that due to the multidimensional and subjective nature of the sense of presence, the most commonly used tools for its measurement are questionnaires. At the same time, the authors note that the number of studies verifying the validity of these tools with respect to specific dimensions of presence

and their sensitivity to individual perceptual differences among users remains limited. Additionally, a literature review conducted by Zhang et al. (Zhang et al., 2025) reveals significant terminological inconsistencies and a lack of standardization in both the definitions of immersion and presence and the methods used to measure them. The authors emphasize the need to clarify concepts and develop a common methodological framework that would enable comparable and replicable research in the future.

2.2. Conclusions resulting from the review

The diversity of applications makes immersion a multidimensional concept, and its definitions and operationalizations vary depending on the theoretical perspective and the purpose of the research. Despite the growing interest in the phenomenon of immersion, there is still a lack of consistent and unambiguous research explaining which factors most significantly determine the intensity of this experience in virtual reality. This applies to both technological conditions, such as the quality of visuals and audio or the dynamics of application performance, as well as psychological, cognitive, and emotional factors, and individual user characteristics. Although the literature on the subject contains numerous definitions and models describing immersion, there is significant inconsistency in methodological approaches and a lack of consensus regarding which variables should be considered crucial for its occurrence and measurement.

Furthermore, the rapid development of VR technology in recent years has led to significant changes in both application quality and hardware capabilities, meaning that the results of studies conducted a decade ago may not reflect current user experiences. Therefore, there is a clear need for contemporary empirical research utilizing the latest technological solutions to better understand the interactions occurring within human-machine systems. At the same time, there is a noticeable research gap regarding the development of reliable, standardized, and replicable measurement tools that enable precise assessment of the level of immersion in VR environments.

A significant limitation of existing research is the insufficient number of experiments conducted with real users, which would allow for empirical verification of the influence of specific factors – technological, psychological, and physiological – on the intensity of immersion experienced. Furthermore, these studies are often based on the analysis of single applications, which limits the generalizability of results. Using diverse VR applications, such as games, simulations, or training tools, with varying levels of quality and character, can significantly increase the objectivity and validity of conclusions. In particular, differences in the perception of immersion between different user groups remain poorly understood, suggesting the need to consider variables such as personality type, level of empathy, digital literacy, experience and frequency of gaming and VR use, physiological responses (e.g., heart rate changes), as well as age and gender.

Conducting research on the phenomenon of immersion in virtual reality is therefore crucial given the development of immersive techniques. They are currently outpacing scientific research on their psychological and cognitive impact on users. Reliable, practical, and multidimensional analyses are lacking in understanding what actually influences the depth of immersion and how to accurately measure it.

3. Results and Remarks regarding Immersion from Authors own Research using VR Technology

The author has already conducted several exploratory and applied studies using virtual reality technologies in various contexts, including entertainment, tourism, and vocational training. Although these studies were conducted independently and were not originally designed as a single research program, they provide valuable preliminary insights into how users perceive and evaluate immersion in VR environments. Importantly, these studies were conducted with diverse samples, using different applications and scenarios, allowing for the identification of recurring patterns rather than application-specific effects.

In the first study presented in this article, respondents using virtual reality were asked to rate selected features of VR and VR games. Respondents used entertainment gaming applications. The VR users were participants of the Researchers' Night (pl Noc Naukowców). The author of this article led VR workshops, and participants voluntarily completed a survey after the workshops. The survey listed various features, which were to be rated on a Likert scale of 1 to 5 after using VR. The results (Figure 1) show that features such as innovation, attractiveness, and immersiveness received the highest ratings. This indicates that immersion is intuitively recognized by users as one of the fundamental attributes of virtual reality experiences. Even without a precise definition provided to respondents, immersion emerged as a relevant and meaningful concept. This finding suggests that immersion functions as a perceptually accessible and experiential construct, warranting further theoretical refinement and systematic research.

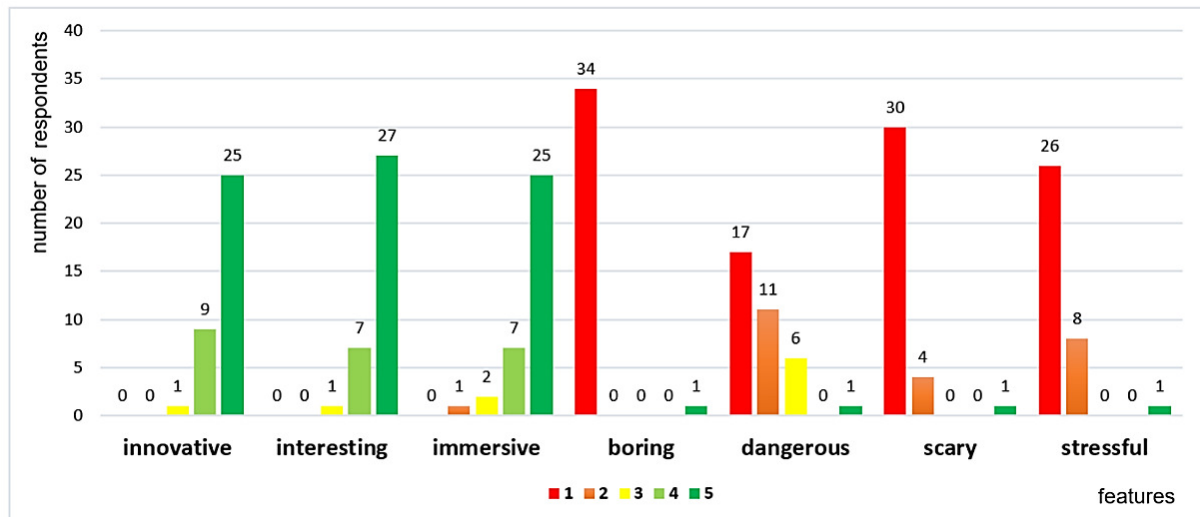


Figure 1. Responses to the question "How would you describe the features of virtual reality and its games?" (where 1 – I disagree; 5 – I agree) for $n = 35$.

Further evidence of immersive potential was obtained in a study involving a VR-based training application for gantry crane operators. This was a larger study that involved participants assuming the role of a gantry crane operator. Here, too, participants completed a survey after the VR session. One question asked participants to rate the extent to which they felt present in the operator's cabin and forgot that they were interacting with a virtual environment. In other words, this was a question about VR immersion, but the phenomenon of immersion was not explicitly articulated in a one word but rather was included in the question descriptively. As shown in Figure 2, nearly 80% of respondents rated this sense of presence and immersion as at least 3 out of 5, and over 50% rated it as 4 or 5. These results demonstrate that high levels of immersion can be achieved not only in entertainment-oriented VR applications but also in professional training scenarios focused on hard technical skills. This finding highlights the practical importance of immersion and supports the need to identify the factors that enable such deep engagement in applied VR contexts.

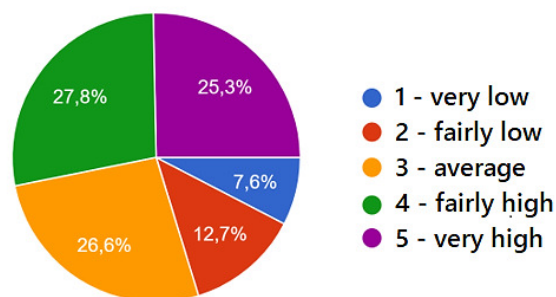


Figure 2. Percentage of responses to the question "To what extent did you feel like you were in the operator's cabin of a gantry crane, forgetting that it was virtual reality?" (where 1 – very low, 5 – very high) for $n = 79$.

Another exploratory author's study, partial results of which can be read in articles (Naramski, Stecula, 2025; Stecula, Naramski, 2025), involved site visits using the Google Earth VR application. Participants used VR to visit real-world locations of their choosing, such as

cities, buildings, or monuments. They then assessed selected features of VR and VR experience in a survey. One question asked respondents about their level of engagement. The VR experience evaluation revealed a high level of engagement, with most respondents rating the VR travel experience as engaging (40,5% of participants) or very engaging (34,9% of participants). Figure 3 shows the results. The average value of this evaluation is 4,01. These results suggest that even applications of an exploratory nature, devoid of dynamic action or elements of competition, can generate a high level of engagement. According to some definitions cited in the literature (above), the level of engagement is also related to immersion. Therefore, it would be worthwhile investigating precisely what factors influence immersion.

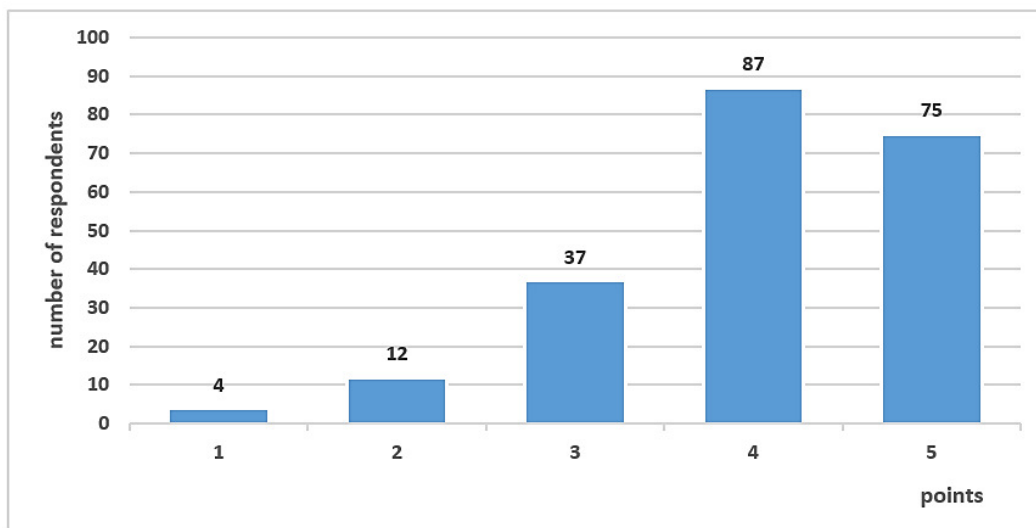


Figure 3. Responses to the question "How engaging was the VR experience for you?" (where 1 – not at all engaging, 5 – very engaging) for n = 215.

The results from these various author studies (Scientific Night, gantry crane operator training and VR visiting place) show that immersion in VR (whether explicitly named or not) is a phenomenon rated quite highly by those using this technology. As the above studies show, VR immersion was intuitively recognized and assessed by the participants. It can be concluded that immersion is a significant and recurring phenomenon in the VR experiences discussed.

The presented results of the authors' research, although conducted in different research contexts and using different VR applications, create a coherent picture of the virtual reality user experience. Their common denominator is the fact that participants – regardless of the purpose of using VR (entertainment, vocational training, virtual tourism) – consistently rated the experience of immersion in the virtual environment highly. Importantly, immersion was recognized and assessed by the participants both directly (through the use of the term "immersive") and indirectly, through descriptive questions referring to the sense of presence, engagement, and "forgetting" the real world. Immersion is not a phenomenon limited to entertainment applications but also occurs in training environments and in cognitive and exploratory applications.

Another important finding from the analyses is that immersion was assessed intuitively, without prior definition or explanation of the concept. Participants used their own understanding of immersion, referring to aspects such as engagement, sense of presence, emotions, and attention span. This indicates that immersion functions in the user experience as a subjectively experienced, yet multidimensional and heterogeneous construct. At the same time, it highlights a fundamental limitation of previous research, discussed in the literature section: immersion is measured fragmentarily, often using single questions or intuitive scales, without distinguishing between its cognitive, emotional, and physiological components.

4. Identification of the research gap

All the presented results therefore serve as exploratory studies that do not aim to provide definitive answers to the question of what immersion is, but rather indicate that it is a real, repeatable, and important element of VR experiences. At the same time, they reveal a methodological gap consisting in the lack of consistent, standardized, and multidimensional tools for measuring immersion that would enable comparisons between different applications, contexts, and user groups.

In this sense, the authors' research provides empirical support for the need for further, in-depth analyses of immersion in virtual reality. They demonstrate that immersion is a universally experienced phenomenon, but, as the literature review demonstrates, it remains poorly operationalized.

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It should be emphasized that there are no scientifically developed measures that allow for a reliable and unambiguous determination of the level of immersion. In practice, it is common to hear statements that a given VR application is "immersive". However, the meaning of this concept is imprecise, and the use of the term itself is often intuitive. Therefore, there is a need to precisely define what immersion actually is and how it can be described, classified, and – particularly important from a research perspective – measured. For comparative and

evaluation purposes, it is necessary to develop an indicator or set of indicators that would allow for a quantitative and repeatable assessment of the level of immersion. This could include both subjective methods (e.g., standardized questionnaires) and objective measurement techniques (e.g., biometric data: heart rate, eye gaze analysis), as well as analysis of user behavior in the VR environment. The following research questions should therefore be addressed in future research:

- How to define immersion in virtual reality?
- How do users experience immersion in the virtual world?
- What are the key variables influencing immersion in virtual reality?
- What influences the level of immersion in virtual reality?
- What are the latent factors of immersion in virtual reality?
- How to operationalize immersion in virtual reality?

This article, therefore, is a discussion of the definition and measurement of immersion. It also serves as a starting point for practical research.

5. Conclusions

This paper discusses the issue of the immersion concept in virtual reality. It presents the overview of definition and understating of immersion in different scientific disciplines. The aim of this article was to collect and organize existing definitions of immersion, identify the main research directions, and identify research gaps related to the understanding and understanding of immersion. The literature review confirms that immersion is a multidimensional and interdisciplinary concept, functioning simultaneously in technical, social, and psychological sciences. Despite numerous attempts to define it, there is still no single, coherent, and universally accepted definition of immersion or a unified model explaining the mechanisms of its development. Research most often focuses on either technological aspects (e.g., graphics quality, sound, interaction) or selected psychological factors, rarely integrating these two approaches comprehensively. The lack of standardized tools for measuring immersion in VR remains a significant research gap. Furthermore, there is a noticeable shortage of empirical studies conducted with real users in near-natural conditions, using various types of VR applications. In this context, the author's own research results, presented in the article, are of particular importance. They were conducted in various contexts of virtual reality use, such as entertainment, training, and virtual tours. Although these studies were exploratory in nature and conducted independently, their results demonstrate a consistent trend: immersion is intuitively recognized and rated relatively highly by users.

The results and observations presented in this article provide a starting point for practical research on the phenomenon of immersion in VR. Further, in-depth research should be undertaken into the mechanisms of immersion, its technological, psychological, and emotional determinants, and the development of tools enabling its comparable measurement.

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ACTIVITY-DRIVEN APPROACHES IN CHINESE LANGUAGE EDUCATION: ENHANCING STUDENT ENGAGEMENT AND EFFECTIVENESS

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Purpose: The analysis focuses on identifying the teaching methods and formats that most impact students' learning effectiveness, to prepare a model for developing academic self-efficacy in the next phase.

Design/methodology/approach: This study is the first phase of a project examining students' academic self-efficacy in learning Chinese. It was conducted through structured interviews with 51 Chinese language teachers from 17 countries.

Findings: Surveys have indicated that the most effective learning occurs through activity-based practical classes and a partnership between students and teachers, while lectures remain essential for conveying theoretical knowledge. At the same time, the study showed that commonly used teaching methods often diverge from students' preferences, reflecting a teacher-perceived mismatch that may hinder learning outcomes. The above constitutes a basis for future research on aspects of academic self-efficacy.

Originality/value: This text is intended for academics and teachers who integrate Chinese into their study programs to build qualifications for knowledge processing and enhance the competitiveness of their graduates in the labor market. It is also aimed at entrepreneurs and managers, including foreign trade specialists, and decision-makers who value investing in human capital and consider it an essential element of economic growth. The principal value of the conducted research is the creation of a basis for a model of academic self-efficacy. The text also presents the observations of Chinese language teachers focused on such aspects as: 1) fears that universities will lose part of their culture and specificity; 2) comparisons of the relationship between a Chinese language teacher and a student to the relationship in a craft workshop; and 3) lack of due attention to the issue of the heavy time burden of teachers preparing thoroughly activating teaching activities.

Keywords: active learning, activating teaching methods, learning Chinese, human capital development, knowledge-based economy.

Category of the paper: Research paper.

1. Introduction

Human capital is defined as having the potential to support regional development, while investments in education and skills are considered central to comprehensive development strategies (Biedka, 2021). It is also described as a resource for the organization's competitive advantage and employee satisfaction (Gitling, 2024). The development of human capital involves investing in knowledge, skills, abilities, health, worldview, cultural level, professional experience, psychophysical factors, physical skills, and vital energy, increasing the value assigned to a given person. It is also treated as a source of future income for both the individual and the organization. Investments in human capital are difficult to measure, costly, and yield long-term returns. However, the size of the investment depends, among other things, on the uniqueness of the capital involved. Organizations or individuals can undertake these investments (Gołaszewska-Kaczan, 2014).

Learning foreign languages is associated with expanding professional competencies, which also foster the development of other skills, such as creativity, problem-solving, cross-cultural understanding, and adaptability to market changes. Mastering a foreign language is one of the most valued competencies in the labor market and a significant indicator of the quality of human capital (Terelak, 2025). Speaking Chinese is considered an exceptional skill due to its unique nature, including the need to explore its writing and tonal nuances, as well as exposure to a vibrant culture. From the perspective of potential economic benefits, mastering Chinese is linked to the world's second-largest economy, which has demonstrated high resilience and maintained a relatively stable rate of growth (Wang, 2026). Forecasts indicate that China's real GDP will grow by 4.8%, exceeding the previous estimates of 4.5% (Goldman Sachs, 2026). In this country, after a period of investing in infrastructure and material assets, the need for increased investment in human capital, an investment also oriented towards economic and social development, is now being emphasized (Yang, 2025).

In this article, the authors present the results of research conducted among Chinese language teachers, focusing on the teaching methods and approaches that have the most significant impact on increasing students' learning effectiveness in Chinese. Particular attention is paid to active learning methods, which provide important assistance in the development of human capital.

Active learning issues are part of one of the biggest research trends. Scholars are pointing out to the timeliness and relevance of the use of active methods in education, through which learners have the opportunity to actually interact within the framework of the material being learned, learn through experience and face educational challenges that foster independent acquisition of knowledge and skills (Roberts, 2019; Reilly, Reeves, 2024). Active learning is characterized by three components correlating with learning activity, namely intellectual, social and physical elements (Edwards, 2017 after Dewey, 1924; Williams et al., 2022) and includes

a very broad group of methods and tools, which in-class problem solving, think-pair-share, role play (Andrews et al., 2022), debates (Mellgren, Ivert, 2016), group work, peer feedback, jigsaw classroom, flipped classroom, team-based learning (Thiele, 2024), asking questions, discussion, watching videos, playing games, solve case-studies, mind mapping (Estonian Entrepreneurship University of Applied Sciences, 2021), 6 Thinking Hats, K-W-L, snowball, placemats, My Little Book Methodology, Card Ranking, Five Questions, Diamond Ranking, In the Hot Seat, Concept mapping, Using Photographs, Conscience Alley, Skimming (PDST, n.d.), etc. Active learning methods are designed to be used when teaching different age groups, at different stages of education - both in schools (Diković, Gergorić, 2020; Mandelid, 2024) and in universities (Dejene, 2019; Thiele, 2024). Active learning is relevant to many scientific disciplines. This is indicated by studies focusing on various active learning tools used when teaching subjects within various sciences - from engineering and science to natural sciences, medicine and social sciences. The research conducted on active learning is dominated by qualitative methods involving groups of several to several dozen students or teachers (Snyder, 2003; Liao, Ringler, 2023; Cai, Wang, 2020; Starns et al., 2021; Inra et al., 2017). An analysis of scholarly works on the use of active learning methods allows us to conclude that they are described as methods that foster increased learning effectiveness, student engagement and interest (du Rocher, 2020; Andrews et al., 2022), and improve learner performance (Bloomer Green et al., 2018), as well as methods that encourage collaborative learning and problem solving (Ito, 2017).

2. Methods

The research results presented in this article constitute the first phase of a project focused on examining the academic self-efficacy of students learning Chinese. Academic self-efficacy is an individual's conviction in their ability to plan, implement, and control the behaviors required to achieve particular educational objectives or complete scholarly assignments. We assumed that it is based on the following elements: 1) teaching formats, 2) preferred teaching methods, 3) factors influencing students' motivation to learn, and 4) student behaviors. This stage involves seeking answers to the question which teaching methods and approaches have the most significant impact on students' learning effectiveness in Chinese. Finding these answers in the next stage will help create a model for selecting teaching methods to shape academic self-efficacy. Our study employed a mixed-methods approach and was conducted among teachers of Chinese language. It focused on structured interviews using a survey. The questionnaire used a 10-point linear scale, with 1 representing the minimum and 10 the maximum. Additionally, respondents could supplement their responses with individual comments for each question. Categories such as “coaching”, “mentoring”, “tutoring”, “blended

learning”, and “m-learning” in the materials presented to the study participants were accompanied by examples placed in parentheses to standardize their interpretation.

The research questionnaire included questions on respondents' sociodemographic data (Table 1) and factual questions on methods and forms of Chinese teaching, students' motivation for learning Chinese, and the behavioral styles of modern students.

Table 1.
Profile of respondents

Parameter	Data (no. of participants)
Countries	Albania (6), Bosnia and Herzegovina (2), Bulgaria (4), Croatia (2), China (8), Czech Republic (4), Estonia (1), Hungary (7), Latvia (1), Lithuania (1), Netherlands (1), Poland (3), Portugal (4), Romania (1), Serbia (3), Türkiye (2), Ukraine (1).
Age	18-25 (2), 26-35 (18), 36-45 (16), 46-55 (12), 56-65 (3)
Place of employment	city > 500 thousand (27), city 150 thousand-500 thousand (11), city 50 thousand-150 thousand (7), city up to 50 thousand people (5), village (1).
University/school	public (48), private (3).
Professional/academic title	bachelor/engineer (6), M.A. (22), Ph.D. (14), associate professor (6), professor (3).
Position held	teaching (17), teaching and researching (34).
Form of employment	fixed-term contract (35), indefinite-term contract (16).
Years of work as a teacher	up to 5 years (18), from 5 to 10 years (8), from 11 to 15 years (9), from 16 to 20 years (6), more than 20 years (10).
Form of subjects taught	traditional (30), online (2), hybrid (19).

Source: own study.

The study took place during the 11th symposium/training for Chinese language teachers residing in Central and Eastern Europe, from November 16-20, 2023, at the Institute of East Asian Studies of Eötvös Loránd University in Budapest. The symposium provides an opportunity to create a platform for academic exchange (including language exchange), joint development, cooperation, and exchange of knowledge and experience. It has positive implications for the development of Chinese teaching and promotion in Europe. In their speeches, the organizers of this symposium/training emphasized that the training center should adapt to the changing landscape by focusing on talent development—Chinese-language speakers with professional skills—while responding to market needs (Li, 2023). Most interviews were conducted in person, with some conducted online after initial contact. Fifty-one interviews were conducted among academic teachers from 17 countries.

3. Results

The academics were asked to rate on a scale of 1 to 10 the overall degree of effectiveness in learning Chinese of two traditional forms of class delivery. Lecture was presented as a form of class based on the use of instructional methods such as informative lecture. Practical classes were presented as forms based on practical-technical activity involving the use of the following

methods: 1) activating methods based on creative cognitive activity and problem solving, 2) expository methods requiring experiential learning and based on emotional-artistic activity, 3) software-based involving information technology.

The vast majority of the surveyed academics believe that practical classes based on activation, expository and program methods have a higher level of effectiveness in learning Chinese compared to lectures based on instructional methods. Practical classes received an average grade of 8.69, while lectures scored 7.57. An analysis of the distribution of grades obtained by the mentioned forms of teaching (Figure 1) shows that 84% of all respondents gave grades of 8 to 10 to practical classes, including 49% who gave the highest grade, 10. In contrast, 65% gave a grade of 8 to 10 to lectures, but 10 was given by only 3 teachers (6%). The standard deviation in the ratings of individual respondents shows a slight difference in opinion regarding the evaluation of the effectiveness of practical classes and lectures, which indicates a fairly high level of reliability of the average ratings obtained by the mentioned forms of classes.

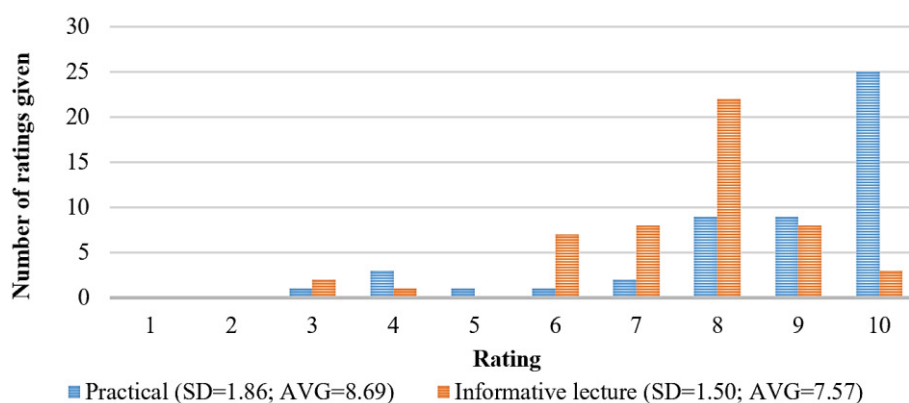


Figure 1. Chinese learning effectiveness ratings distribution.

Source: own study.

Closed questions were accompanied by comments from respondents showing their personal viewpoints and teaching experience. For example, the statement of respondent R15 draws attention to the difficulty in modern defining and distinguishing between lectures and practical classes: *Lectures can also include activation elements. I include QR codes embedded in the slides, students read the codes and are redirected to additional tasks that consolidate the theoretical content.* Another statement emphasizes the complementarity of the two methods, as well as elements attributed to the organizational culture of the universities (R30): *I know that activation methods are effective. I myself learn faster by doing various tasks. However, if we fully abandon instructional methods then universities will lose part of their culture, their specificity. Universities are not only about the lecturer's monologue, but also about discussion, however, it should at the higher level be based on the theory presented first by instructional methods.*

The questions in the next section of the questionnaire referred to the evaluation of the effectiveness in learning Chinese of innovative forms of instruction, namely E-learning - synchronous remote learning, Blended learning (hybrid learning, for example: lecture - online;

exercises - in the classroom), M-learning (e.g., complete independent learning based on teaching materials available on the e-learning platform), Mentoring (partnership relationship between professor and student), Tutoring (e.g., individual consultations), and Coaching (individual work with a professor, allowing the student to recognize their skills, abilities, and talents and to use their potential more fully).

The analysis of the answers given by the respondents regarding the effectiveness of innovative forms of teaching made it possible to rank these forms according to the ratings obtained (Figure 2). The results of the analysis show that academics consider Coaching, Mentoring and Tutoring to be the most effective forms of teaching Chinese, i.e. forms of teaching that are based on partner relationships and allow individual work of the student with the academic teacher. Coaching, Mentoring and Tutoring received average ratings of 7.84; 7.82 and 7.76, respectively, out of a possible 10. Next in the ranking was Blended learning with an average rating of 7.35 and E-learning with a rating of 6.20. The last place in the ranking is occupied by M-learning with a rating of 5.88, i.e. the form of instruction where the student is left alone most of the time has the lowest level of effectiveness in learning Chinese. Such results speak to the fact that for effective Chinese learning, direct contact between the student and the academic teacher is essential, despite the fact that the modern student is eager to use Internet technologies.

An analysis of the standard deviation and the distribution of scores obtained by each innovative method of instruction (Figure 3) shows that there are forms in the evaluation of the effectiveness of which academics have a similar opinion, and there are forms of instruction that can challenge discussion. Surveyed Chinese language teachers share a similar opinion on the leaders of this ranking, i.e. such innovative forms of classes as Coaching, Mentoring and Tutoring. 84% of all respondents rated the effectiveness of these methods at 7 to 10. In contrast, the opinions of university teachers differ on the effectiveness of Blended learning, E-learning and M-learning in Chinese language acquisition.

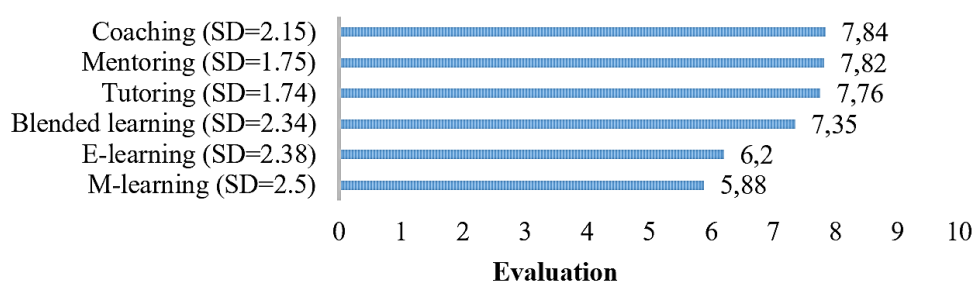


Figure 2. Ranking of innovative instruction effectiveness.

Source: own study.

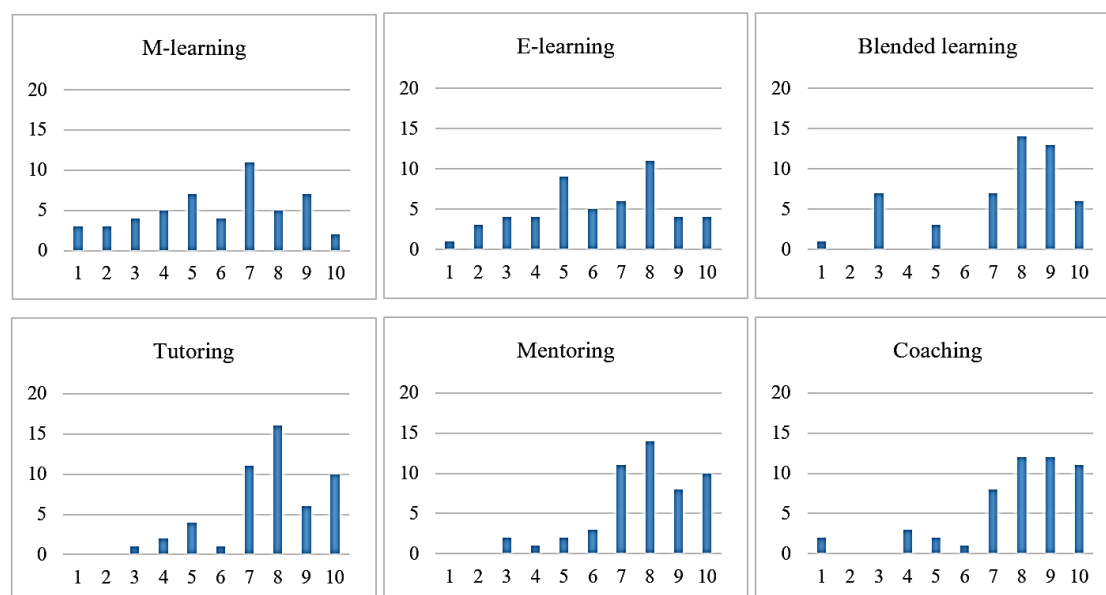


Figure 3. Distribution of marks in innovative teaching.

Source: own study.

Respondent R7's statement underscores the importance of an individual approach and a good relationship between lecturer and student combined with activity-based methods: *The most effective way of learning today resembles the relationship between craftsman and student. It is a personalized relationship, tailored to the special needs of the student. It is a relationship that supports and builds a bond. A bond that is not possible to build during instructional methods, but is possible in case of activating forms.* Such an act of research has shown that the modern student needs forms of teaching based on direct interaction with the academic teacher.

University teachers were also asked to evaluate the effectiveness in learning Chinese of selected groups of teaching methods, namely Instructional methods, activating methods, expository, software-based. Analysis of the respondents' answers made it possible to develop a ranking of the above-mentioned groups of teaching methods according to the average scores obtained (Figure 4). According to academics, the greatest effectiveness in learning Chinese is characterized by activation methods, i.e. methods that strongly connect the educational process with social and professional life and require very high involvement of students in the learning process. Second place in the ranking is occupied by Instructional methods with an average score of 7.47, Third place belongs to software-based. The last place in the ranking of effectiveness is occupied by expository methods.

An analysis of the distribution and standard deviation of the ratings obtained by each group of instructional methods (Figure 5) shows consistency in opinions regarding the evaluation of the effectiveness of activating methods and instructional methods. However, in the case of the effectiveness of software-based and expository methods, the respondents do not present a homogeneous opinion.

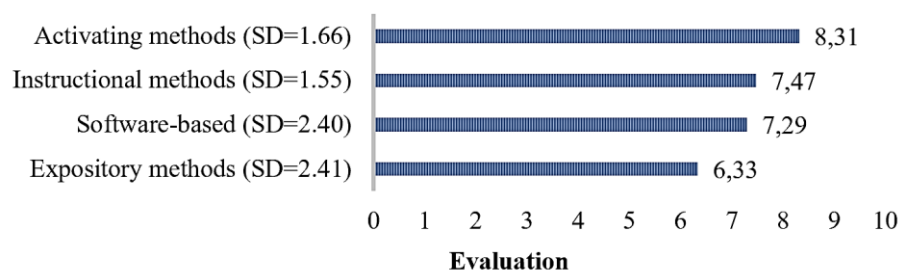


Figure 4. Ranking of teaching methods by effectiveness.

Source: own study.

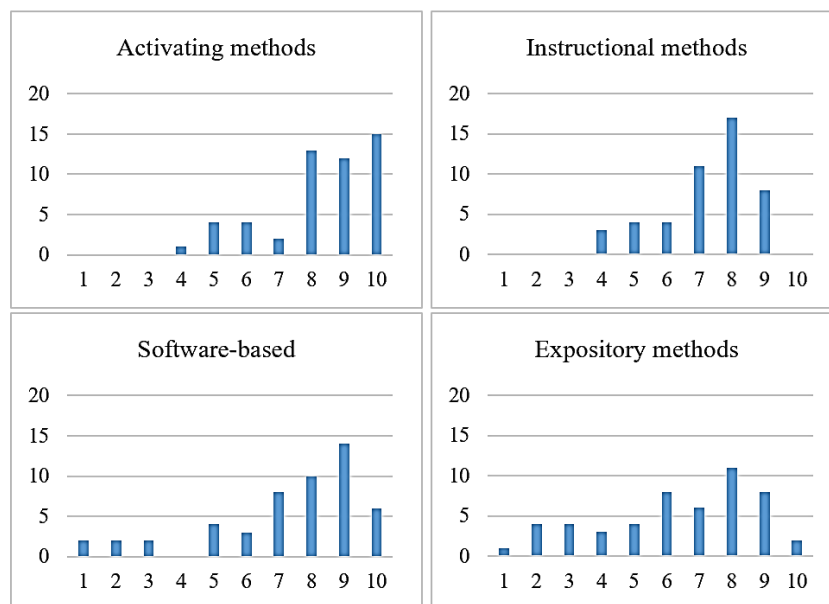


Figure 5. Ratings distribution by teaching method groups.

Source: own study.

In conclusion, we can say that the clear leader in the ranking of effectiveness is Activity-based methods, however, university teachers still consider it essential to use Instructional methods as a tool for conveying theoretical foundations in the process of teaching Chinese. Software-based and Expository methods are also popular among Chinese language teachers, but the respondents' opinions regarding their effectiveness vary considerably.

On the other hand, in their statements, respondents pay attention to other levels of application of activation methods - fashion and expectations of employers / management: *Activating students is nowadays not only a fashionable didactic approach, but also a kind of expectation articulated by superiors - managers of higher education institutions. A modern teacher should activate, and if he or she does not do it, then he or she should learn to do it as soon as possible, because only this method is effective (R17).*

Similarly, the statement of respondent R6 points to an additional aspect - the issue of engaging costs incurred by a teacher using activation methods (shown in terms of time) and the need to address other topics than before - the underestimation of teachers involved in preparing activation classes: *Activation methods have a lot of advantages and are the current standard in*

language teaching. However, little is said about the amount of time a teacher should engage in mastering new tools, especially online ones, how much additional time is needed to prepare fully activating teaching activities (R6).

The next question measured the extent to which activating methods are used in the practice of teaching Chinese. In response to the question "Please indicate to what extent activating methods are used in the organization of the educational process at your university", 13.73% of respondents indicated that at their university, activating teaching methods are used to a "very high degree", 62.75% of respondents indicated a "high degree", 15.69% - recognized a "medium degree", while only 7.84% of respondents felt that such methods were used to a "low" and "very low" degree (Figure 6). In other words, the vast majority of respondents (76.48%) felt that activating teaching methods were used to a high degree at their universities.

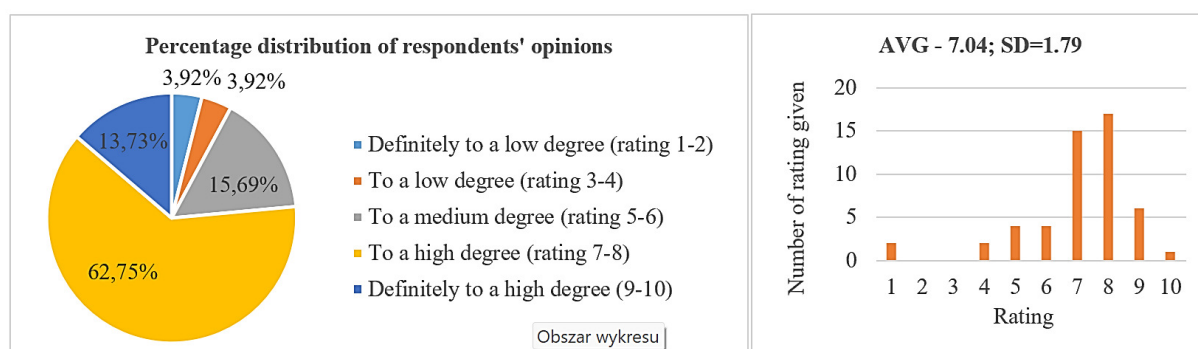


Figure 6. Evaluation of activation methods usage in education.

Source: own study.

In the next part of the interview, questions were included to evaluate the degree of use of the various teaching methods that Chinese language teachers may have encountered in the course of teaching. The evaluation concerned the following teaching methods: informative lecture, Discussion, Questions & Answers, Case Study, Debate, Brainstorm, Decision tree, Outdoor activities, Design method, Snow Ball, SWOT analysis, Fish skeleton type diagram, Mind map, Teaching games, Specialized software. In case the academic teachers did not have to deal with the indicated teaching methods, they could mark "Not applicable".

100% of our respondents use methods such as Informative lecture and Discussion in their Chinese language teaching practice; 96.08% - Questions & Answers and Debate, 92.16% - Case Study. Next in the popularity ranking go Brainstorm and Teaching games – 88.24 and 82.35% of respondents respectively, followed by Specialized software and Outdoor activities – 76.47% of surveyed university teachers, Design methods - used by 70.59% of teachers, Mind map – 68.63%, Decision tree - 66.67%, SWOT analysis type methods (52.94%), Fish skeleton type diagram and Snow Ball used by less than 50% of all respondents (Figure 7). Analysis of the responses indicates that all the methods mentioned, except Informative lecture, Chinese language teachers refer to activation methods useful in practical classes.

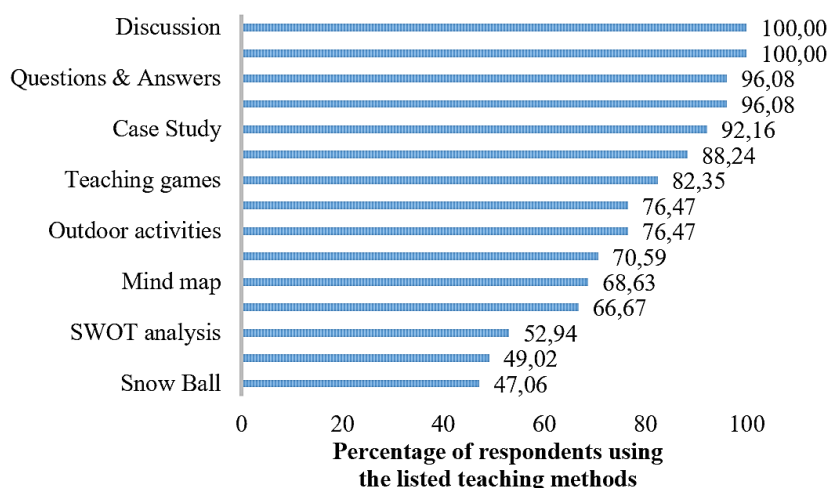


Figure 7. Ranking of selected teaching methods usage in Chinese learning.

Source: own study.

Respondents in the comments pointed out that *Students more interested in activation methods than in instructional ones. Especially teaching games on mobile devices. They put down their smartphones and get sad, when they take them in their hands again it brings them to life again.* (R12) and *Activation methods allow students to get into the flow. In some of the games and tasks [students] get totally involved, without considering that they are playing in Chinese and not in their native language. And yet, while playing they also learn, they learn how to talk to another player, how to negotiate and communicate their point of view, their emotions, their joy or dissatisfaction* (R17). In such a way, our interview showed that the set of teaching methods, most often used in the didactic process, does not always meet the preferences/needs of students, which negatively affects their ASE.

In the next pool of questions, the academics were asked to determine the impact of activation methods on improving their students' skills, knowledge and competencies while learning Chinese.

In response to the question asking to specify how the activating methods influence improving students' skills, knowledge, and competencies, 80% of respondents marked "high" and "very high" influence of activating methods on improving students' skills, knowledge, and competencies in learning Chinese; "medium influence" was marked by 14% of respondents, and "low influence" by only 6% of respondents (Figure 8). In conclusion, it can be said that from the point of view of most university teachers, the use of activating teaching methods has a high impact on improving the effectiveness of the learning process.

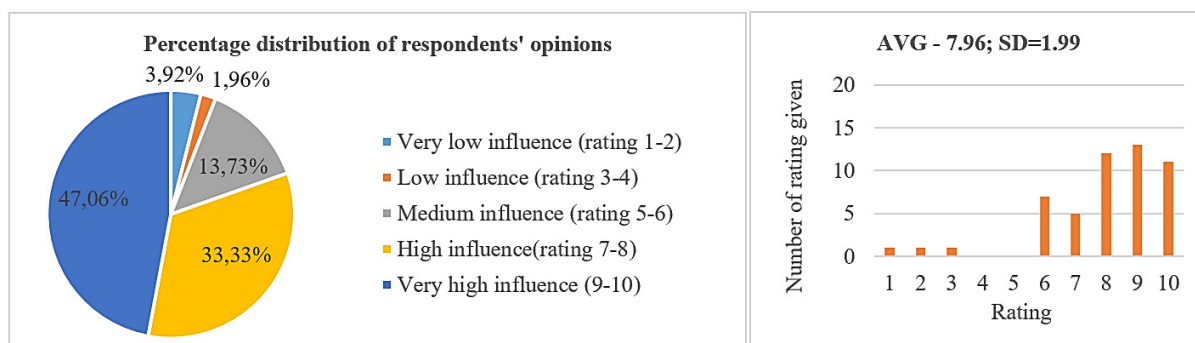


Figure 8. Impact of activation methods on skill development.

Source: own study.

In addition to those mentioned, according to the teachers surveyed, the effectiveness of the educational process is influenced by further training of teaching staff in the space of active methods: *We represent different countries here, but active learning is an international category. Regardless of the origin, the university represented, the level or the system introduced - the language is now mainly taught actively. When I was studying, a lot depended on the character or maybe temperament of the instructor. One was more communicative and energetic - the other more introverted and focused on tabular data, now, regardless of the personal characteristics of the teacher, everyone tries to activate. These are not casual activities, but more planned, perhaps even systemic. There is more and more training, better and worse, but more and more available. The most important thing, then, is the availability and quality of these trainings - they have an impact on the effectiveness of the educational process (R18).*

In the next part of the survey, university teachers were asked to answer a question about the extent to which they agreed with statements related to activating teaching methods, such as case studies and educational games, that enhance students' engagement, curiosity, independence, and ability to self-assess in the learning process. The opinions of university teachers on the above statements provided additional confirmation of the positive impact of active teaching methods on students' effectiveness in learning Chinese. Figure 9 shows the ranking of responses according to the average rating of each issue. According to this ranking, the majority of academics agree that the use of activating methods increases the student's mental activity and level of engagement in learning - the first ranking with an average rating of 8.67. The second position in the ranking with an average rating of 8.29 is occupied by the question regarding whether activation methods provide an opportunity for the teacher to increase the degree of interest in the subject. 78% of the surveyed university teachers that the use of activation methods in the study of Chinese gives students the opportunity to demonstrate their independence and leads to their own self-assessment (Figure 10) engagement in learning, increasing interest in the subject matter of the class and opportunities to demonstrate independence: *I activate students within each group I teach, so I have no reference to non-activated groups... I can say, however, what pleasantly surprised me - I was surprised by the change in their voice. A change that can be heard when they are having fun while learning,*

only then do they open up more and allow me into their inner world. You can see then whether they like to compete with each other, show their independence or prefer group work more - cooperative. You can see, for example, that some people are shy and quieter at the beginning of the classes, and thanks to the activation activities they themselves start to speak louder and even activate others and emphasize the connection of a particular game with the material being covered (R20).

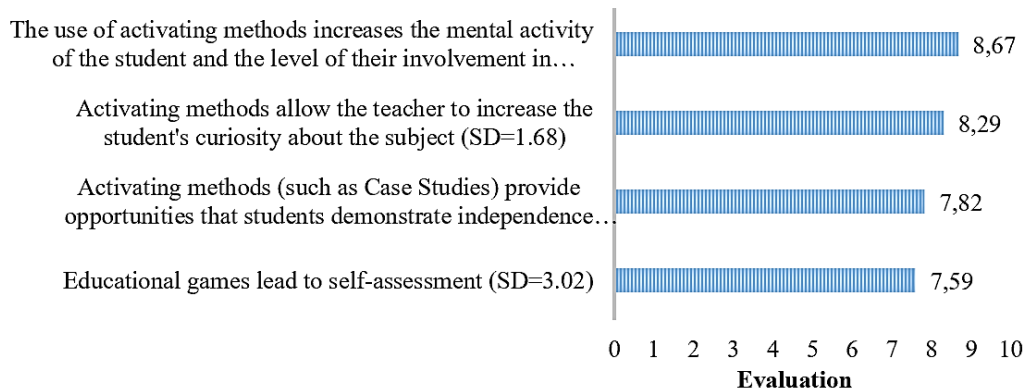


Figure 9. Ranking of responses by average rating per issue.

Source: own study.

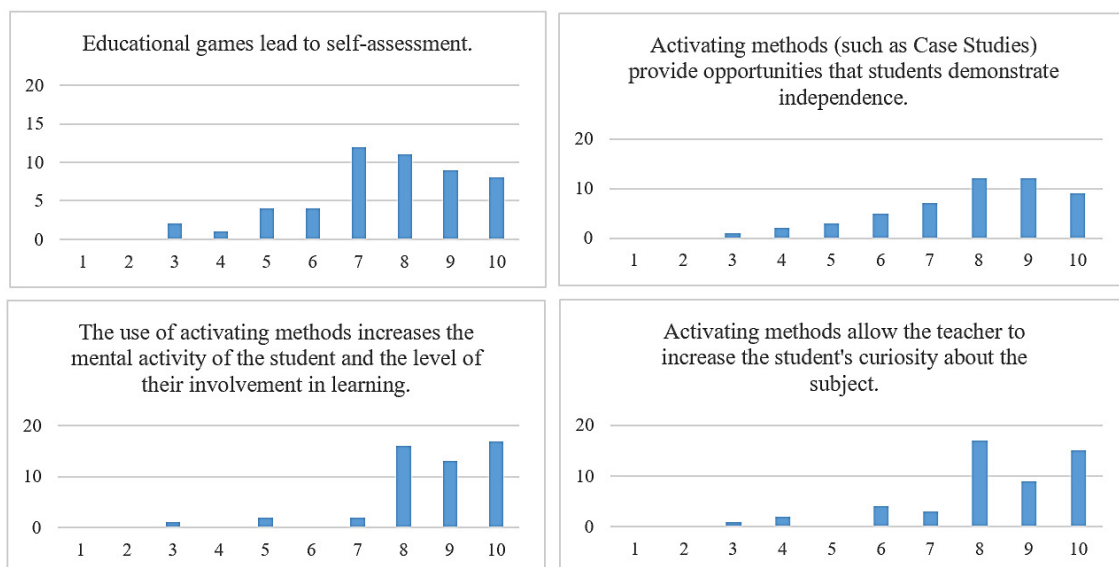


Figure 10. Distribution of ratings across individual issues.

Source: own study.

An analysis of the ratings given to the effectiveness of each teaching method made it possible to rank these methods (Figure 11). Among the most effective methods for learning Chinese, academics rank Questions & Answers, Teaching games, and Discussion. The next four places in the ranking are taken by Debate, Brainstorm, Case Study and Specialized software. Such a method as Informative lecture is ranked eighth in the compiled ranking. The rest of the selected teaching methods have ratings in the effectiveness ranking from 7.25 to 5.56.

Analysis of the distribution of evaluations of individual teaching methods and analysis of the standard deviation in the evaluations of individual respondents shows consistency in the evaluation of methods-leaders of the effectiveness ranking: Questions & Answers, Teaching games, Discussion and Informative lecture. However, in the evaluation of the methods Fish skeleton type diagram, Decision tree, Specialized software, SWOT analysis, Outdoor activities and Snow Ball, respondents do not have a homogeneous opinion (Figure 12).

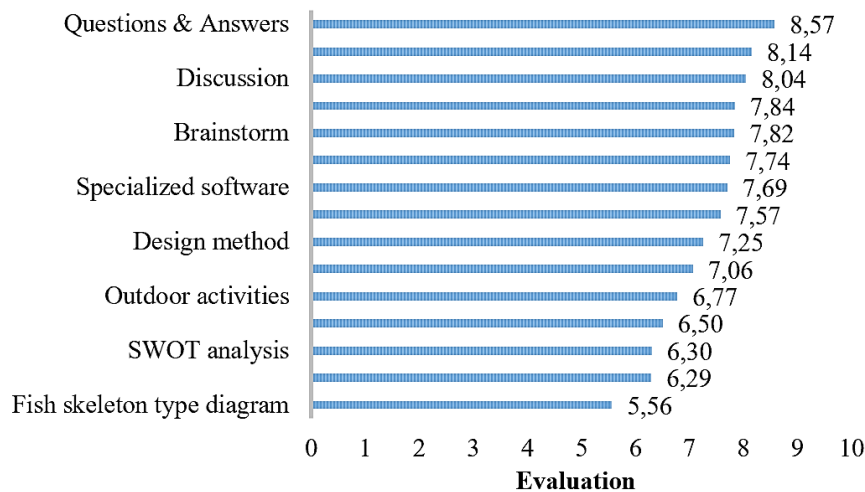


Figure 11. Ranking of selected teaching methods' effectiveness.

Source: own study.

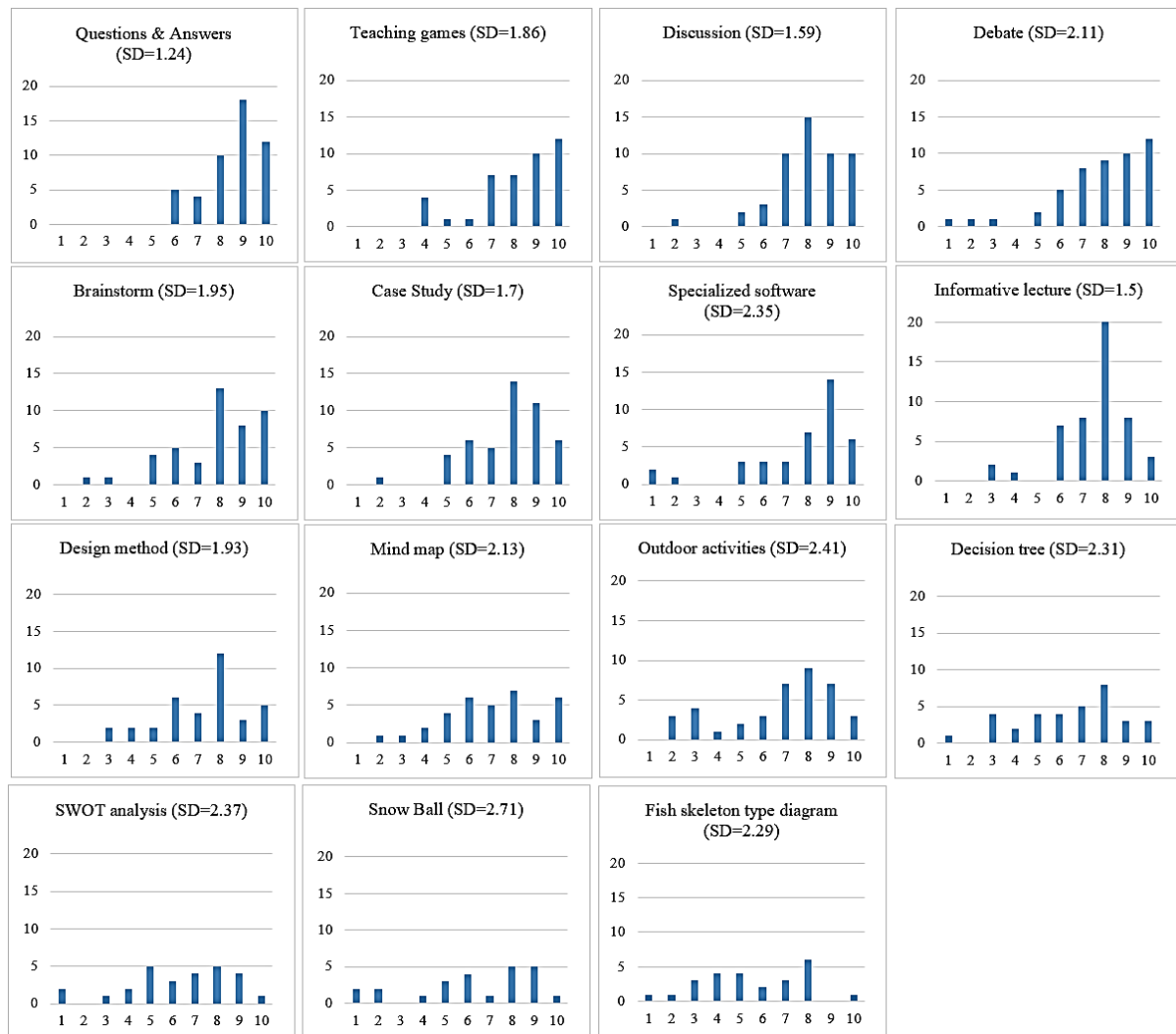


Figure 12. Distribution of grades by teaching method.

Source: own study.

Statements from some respondents point out that particular activation methods are sometimes associated with a particular discipline - dedicated to specific fields of study: *I associate Snow Ball more with a sampling method than a teaching method. You are an economist, is this an activation tool for economics students? (R6)* or *The name fish skeleton excites my imagination a lot, but I haven't heard of it before. Can you give me an idea of how you use it when teaching economics? (R12).*

4. Discussion

Mastering the Chinese language opens up opportunities for students to participate freely in the global circulation of knowledge, giving them access to advanced achievements in science and technology, learning about multidimensional cultural heritage, and actively engaging in the

international academic and professional environment (Nhung, 2024). The results of our study indicate that, despite differences in evaluations of individual teaching methods, activation methods are highly effective in learning Chinese, according to all the university teachers surveyed. As Krajewska notes (2021), active learning in academic teaching is a valuable and effective practice for students and teachers, but its use depends primarily on participants' willingness in the educational process. However Wu (2023) notes, that teaching strategies should be tailored to individual student profiles. This researcher points to the special role of immersive approaches (immersion in an environment of continuous language exposure), based on tasks and gamification, which have particular advantages in language learning (Wu, 2023). Li et al. (2025) also emphasize the importance of supporting students' engagement and motivation in learning Chinese, as well as improving their inclusive participation.

Our study also allowed us to identify three important aspects related to the use of active learning in Chinese language teaching:

- teachers' concerns about universities losing part of their culture and specificity centered around the use of expository methods,
- the possibility of changing the teacher's identity related to the development of a new type of relationship between teacher and student,
- the problem of teachers being overloaded with tasks/working hours related to the need to master and implement new teaching tools.

One identified barrier to implementing active learning is student resistance. It involves developing teaching strategies based on explanation and facilitation to reduce this resistance. The former relies on explaining what learners can expect during the activity – discussing the purpose and its relation to the learning process and assessed tasks. The latter strategy relies on close contact, for example, in the form of a walk around the room, encouraging engagement and asking questions, awarding points for participation in the activity, summarizing exercises, and asking for feedback. A positive correlation has been observed between positive reactions (course evaluations) to the implementation of active learning, increased participation, lower levels of distraction, and the use of these strategies by teachers (Andrews et al., 2022; Tharayil, et al., 2018).

The second type of barrier involves teachers' resistance to the change, which impacts both their work and their identity. Barriers can include heavy administrative workloads and high performance expectations (Marques, Lopes, Magalhães, 2024). According to McCorkle (2021) barriers also include: 1) the time it takes to prepare classes and the duration of classes, 2) the need for staff development, 3) the teaching staff's perception of their role (turning lecturers into facilitators) and value (including motivation to implement changes). Emphasis is placed on the importance of making small changes (better than reorganizing entire courses), developing instructions for implementing active learning, providing ongoing professional development opportunities, creating a space for conversation, implementing changes in organizational culture at the faculty level, providing incentives for additional work, and pushing

themselves to implement new methods regardless of the ones the teachers themselves were trained in (McCorkle, 2021). Researchers' professional identity is presented as a way of perceiving themselves and their work in relation to their discipline and their perceived professional status. Researchers may have a professional identity that does not include teaching or perceive threats to their professional identity within their discipline. Both of these situations can constitute barriers to implementing active learning, thus promoting exclusively traditional delivery methods. These barriers are fostered by, among others: 1) treating training as solely shaping a researcher's identity, 2) fear of revealing oneself as a teacher, and 3) relying on a professional culture of science that considers teaching less critical (Brownell, Tanner, 2012).

Teaching based on active learning is associated with the costs of transforming education, including the challenges described earlier. Brewe et al. (2018) also estimated the total cost of student credit for classes conducted in a traditional format (lecture) and in an active-learning format (modeling instruction). Their research findings indicate that active learning is associated with higher costs, making it less economically profitable for faculty. Administrators find it more profitable to organize classes for larger groups—i.e., groups of over 30 students—requiring fewer staff. The group that benefits most from active learning is students (Brewe, Dou, Shand, 2018). Another type of cost is that incurred by teachers implementing the "new method" in their classes. As Mennella notes (2017), this cost is teacher fatigue during the semester. Emphasis is placed on the need to introduce new solutions for measuring, allocating, and compensating teaching load in an active learning model, as well as preventing burnout associated with excessive additional workload (Mennella, 2017). The aspect of remuneration in the form of a reduced teaching load, financial benefits, recognition for long-term employment, and rewards for teaching is also discussed in the research of other scientists (see: Brownell, Tanner, 2012).

Given the relatively low interest in the discussed issues so far and the lack of systematic research on teachers' time burden, their level of fatigue, and existing institutional incentives, assessing the scale of this phenomenon remains difficult.

5. Summary

The process of teaching Chinese should be based on the development of students' academic self-efficacy. In turn, the academic self-efficacy of the modern student depends on the teaching methods and approaches, the factors that motivate/demotivate the student to learn, and the student's behavior. Surveys of university teachers have indicated that practical classes based on activity-based methods are the most effective for learning Chinese. At the same time, direct contact between the student and the academic teacher, based on a partnership and the teacher's individual work with the student, can be essential. However, such a form of instruction as a lecture must and continues to remain a tool for conveying theoretical foundations in the

practice of studying Chinese at the academic level. It is also worth considering an alternative interpretation that accounts for the low quality of lectures offered for distance learning, for example, using mobile devices.

Academics, in their statements, stressed that the modern student is more interested in activating methods than in instructional ones. The majority of academic teachers agree that the use of activating methods increases students' mental activity and level of involvement in learning, provides students with an opportunity to demonstrate their independence, and, in turn, increases the values derived from learning in functional, emotional, and social dimensions. However, the research indicated that the set of teaching methods most often used in the didactic process does not always align with students' preferences, suggesting a teacher-perceived mismatch that may reduce educational effectiveness.

In addition to the above, the conducted study allowed us to identify three important aspects related to the implementation of active learning methods by Chinese language teachers: 1) fears that universities will lose part of their culture and specificity related to the departure from traditional lectures; 2) comparisons of the relationship between a Chinese language teacher and a student to the relationship in a craft workshop; and 3) lack of due attention to the issue of the heavy time burden of teachers preparing thoroughly activating teaching activities, related, among other things, to the need to master and implement new teaching tools.

This paper addresses academics and educators who incorporate Chinese language instruction into their study programs to develop competencies in knowledge management and strengthen the labor-market competitiveness of their graduates. It is also intended for entrepreneurs, managers, foreign trade professionals, and policymakers who recognize investment in human capital as a fundamental driver of sustainable economic growth.

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AN ALGORITHMIC MANAGEMENT AND THE PARADOX OF THE BANI WORLD: THE BALANCE BETWEEN EFFICIENCY AND HUMAN-CENTRIC LEADERSHIP

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Purpose: This study examines the paradox of algorithmic management in contemporary organizations operating under BANI (brittle, anxious, nonlinear, incomprehensible) conditions. The article investigates how different configurations of algorithmic management contribute to organizational vulnerabilities and how responsible algorithmic management practices can support adaptive and human-centric leadership.

Design/methodology/approach: The study adopts a mixed-methods approach combining a systematic literature review (2020-2025) with secondary analysis of large-scale European datasets, including the AIM-WORK survey and OECD data. Descriptive statistics and cross-tabulations are used to examine the prevalence and configurations of algorithmic management, while theoretical interpretation links empirical patterns to BANI-related vulnerabilities and leadership dynamics.

Findings: The results show that algorithmic management is widespread in European workplaces, particularly in task allocation and scheduling, but its intensity and form vary significantly across occupations and countries. High levels of algorithmic autonomy, opacity, and rigidity are associated with increased organizational brittleness, employee anxiety, and incomprehensibility. Conversely, organizations implementing transparency-by-design, explainable AI, and human-in-the-loop governance exhibit higher trust, perceived fairness, and adaptive capacity. Responsible algorithmic management enables leaders to balance efficiency with empathy, sense-making, and relational coordination.

Research limitations/implications: The study relies on cross-sectional secondary data, limiting causal inference and longitudinal analysis. Leadership outcomes are operationalized indirectly through work-design and governance indicators rather than direct behavioral measures. Future research should employ longitudinal and qualitative designs to explore how responsible algorithmic practices shape leadership behaviors and organizational resilience over time.

Originality/value (research gap): This study addresses a critical gap by empirically linking algorithmic management configurations to BANI-related organizational vulnerabilities and by integrating responsible AI governance with theories of human-centric and adaptive leadership. By combining large-scale European evidence with the BANI framework, it offers a novel perspective on algorithmic management as both a source of fragility and a potential driver of organizational resilience.

Keywords: algorithmic management; BANI framework; human-centric leadership; human-in-the-loop; organizational resilience.

Category of the paper: scientific research.

1. Introduction

The accelerating integration of artificial intelligence and machine learning into organizational life has ushered in an era in which algorithms actively shape managerial practices, decision-making, and communication flows (Murire, 2024; Song et al., 2025; Raina et al., 2026). As firms pursue greater efficiency, responsiveness, and strategic precision, algorithmic systems are increasingly viewed as essential instruments for optimizing processes and amplifying competitive advantage. They enable refined data analytics, streamline workflows, and support decisions at unprecedented speed and scale. Yet this algorithm-driven transformation is accompanied by profound tensions. While algorithmic management promises operational excellence, it simultaneously raises concerns regarding human agency, transparency, and the erosion of relational aspects of leadership. The deployment of opaque or overly rigid systems can undermine trust, complicate communication, and reduce the capacity of organizations to account for emotional, contextual, or intuitive dimensions of human work.

Against the backdrop of a world marked by brittleness, anxiety, nonlinearity, and incomprehensibility (BANI) (Cascio, 2020; Grabmeier, 2020), these tensions become even more pronounced. Algorithmic tools, despite their analytical power, may reinforce fragility by creating overly deterministic structures that fail under unforeseen conditions. They may heighten anxiety among employees who feel surveilled or displaced by automated decision processes, and they often struggle to navigate nonlinear dynamics or ambiguous patterns that defy simple prediction.

This article examines the paradox of algorithmic management within the BANI context, focusing on the delicate balance between organizational efficiency and human-centric leadership. It explores how algorithms can simultaneously enhance performance and destabilize interpersonal dynamics, and how leaders can navigate these contradictions to foster resilient, empathetic, and adaptive workplaces. This study formulates a set of research questions and hypotheses. These are designed to examine specific configurations and design features of algorithmic management, as well as their implications for employee experience, organizational resilience, and the emergence of human-centric leadership.

RQ1: How do different configurations of algorithmic management (level of algorithmic autonomy, rigidity, transparency) contribute to BANI-related vulnerabilities such as brittleness, worker anxiety, and incomprehensibility?

H1: Higher levels of algorithmic autonomy, opacity, and rigidity are positively associated with employee anxiety, reduced autonomy, and increased organizational brittleness.

RQ2: Which design features of algorithmic management systems (e.g., transparency, explainability, meaningful oversight) most effectively mitigate BANI-related vulnerabilities such as incomprehensibility, anxiety, and nonlinearity in workplace decision-making?

- H2: Workplaces that implement transparency-by-design, explainable AI, and strong human-oversight mechanisms show significantly higher employee trust, perceived fairness, and adaptive capacity than workplaces relying on opaque, fully automated AM.
- RQ3: How does the implementation of responsible algorithmic management practices influence the development of adaptive and human-centric leadership behaviours in BANI-affected organizations?
- H3: Responsible algorithmic management positively moderates the relationship between algorithmic efficiency and leadership effectiveness, enabling leaders to balance data-driven decision-making with empathy and relational coordination.

2. Literature review

Research on algorithmic management (AM) has expanded rapidly in recent years, offering increasingly detailed insights into how AI-driven managerial systems reshape work, decision-making, and organizational life. Foundational contributions define AM as the delegation of managerial tasks, such as monitoring, scheduling, evaluation, coordination, and even discipline—to algorithmic systems capable of operating with varying degrees of autonomy, opacity, and rigidity. This body of scholarship shows that algorithmic systems do not simply automate discrete tasks but introduce a qualitatively new mode of managerial control based on prediction, data-intensive processing, and continuous surveillance, which can transform the structure and social fabric of organizations (Möhlmann et al., 2021; Meijerink et al., 2021; Benlian et al., 2022; Parent-Rocheleau et al., 2022). Conceptual analyses also demonstrate that algorithmic systems do not merely execute managerial functions but actively shape meaning-making within organizations by embedding assumptions about efficiency, risk, and performance. These systems influence how work is structured, how decisions are framed, and how managerial authority is enacted, thereby affecting both managerial practice and employee agency. Scholarship highlights that algorithms, as socio-technical actors, configure communication flows, encode particular logics of control, and redefine what counts as relevant or legitimate information in organizational contexts (Gulbrandsen, Just, 2024; Hassan, 2024). Collectively, these works establish the theoretical foundation for understanding algorithmic management as a distinctive managerial paradigm rather than simply a technological tool.

Across empirical contexts, algorithmic management has been shown to profoundly affect job design, employee well-being, and perceptions of fairness. High levels of algorithmic autonomy and opacity often correlate with reduced worker discretion, heightened technostress, emotional strain, and a diminished sense of meaningful work. Continuous monitoring, real-time performance scoring, and automated decision pipelines can amplify employee anxiety, reduce perceived fairness, and restrict opportunities for sense-making, an effect particularly salient in

environments characterized by volatility, ambiguity, and information overload (Kellogg et al., 2020; Zayid et al., 2024; Kinowska, Sienkiewicz, 2023; García-Ruiz, Rocchi, 2025). Studies of gig-work and platform-mediated labor show similar patterns, with rigid algorithmic rules inducing behavioural gaming, dependency, and constrained autonomy (Duggan et al., 2020; Liu, Yin, 2024). The organizational dynamics associated with algorithmic management increasingly reflect the characteristics of the BANI world. Brittleness becomes visible in highly rigid algorithmic systems that struggle to adapt to contextual nuance, creating vulnerabilities whenever unpredictable or rare events occur, which mirrors Cascio's description of fragile structures that appear stable until they suddenly fail under stress (Cascio, 2020). Anxiety intensifies as workers face continuous performance evaluation, automated monitoring, and opaque decision rules, reinforcing the emotional volatility that Grabmeier identifies as central to contemporary organizational environments (Grabmeier, 2020). Nonlinearity emerges from the complex interactions between human judgement, machine-generated recommendations, and organizational processes, where small variations—such as algorithmic recalibrations or changes in worker behaviour—produce disproportionate outcomes, a pattern highlighted in studies examining algorithmic control and job design (Kellogg et al., 2020; Parent-Rocheleau, Parker, 2022). Finally, incomprehensibility results from the increasing opacity of algorithmic decision-making and the difficulty workers and managers face when trying to interpret, contest, or influence automated systems - an issue emphasized in research on transparency, explainability, and human oversight in AI-driven organizational contexts (Shin, 2021; Kritikos, Iphofen, 2024).

Algorithmic management can be understood as a lens through which contemporary organizational dynamics are increasingly interpreted, particularly when analyzed using the BANI framework - brittleness, anxiety, nonlinearity, and incomprehensibility. Conceptually, brittleness reflects the vulnerability of organizations whose processes and decision-making structures rely heavily on algorithmic systems. Rigid task allocation, narrow performance criteria, and inflexible procedural rules reduce adaptive capacity and highlight the fragility of efficiency-driven structures, revealing that apparent stability may mask systemic susceptibility to disruption (Kellogg et al., 2020; Möhlmann et al., 2021; Cameron et al., 2023; Cox, Oosterwijk, 2024). Anxiety emerges as a theoretical construct capturing the persistent uncertainty, perceived unfairness, and emotional strain experienced by workers under continuous algorithmic oversight. The interplay of opaque decision-making, automated performance scoring, and limited autonomy reinforces this tension, positioning anxiety as both an individual and collective response to digitally mediated control environments (Gonzalez Vazquez et al., 2025; Fernández-Macias et al., 2025; Kinowska, Sienkiewicz, 2023; Zayid et al., 2024). The notion of nonlinearity highlights that small changes in human behavior, algorithmic outputs, or organizational parameters can produce disproportionate and often unpredictable consequences. This conceptual lens emphasizes the feedback loops and emergent effects inherent to human-algorithm interactions, providing a framework to understand why

minor adjustments in processes or data inputs can cascade into substantial organizational impacts (Parent-Rochelleau, Parker, 2022; Duggan et al., 2020). Finally, incomprehensibility captures the challenges associated with the opacity of algorithmic systems and the difficulty of interpreting, contesting, or influencing automated decisions. This dimension foregrounds the theoretical need for transparency, explainability, and structured human oversight to maintain meaningful engagement with algorithmically governed work (Shin, 2021; Kritikos, Iphofen, 2024; Papagiannidis et al., 2025). Taken together, these four dimensions offer a synthetic framework for understanding algorithmic management as a complex socio-technical phenomenon. The BANI lens allows scholars and practitioners to conceptualize not only the systemic vulnerabilities, uncertainties, and emergent properties of digitally mediated work, but also the constraints these characteristics impose on leadership, decision-making, and organizational resilience. By integrating these insights, the framework underscores the need for human-centric organizational approaches that balance algorithmic efficiency with interpretive capacity, ethical accountability, and adaptive responsiveness (Cascio, 2020; Grabmeier, 2020).

Cross-national analyses of algorithmic management reveal substantial variation in how these systems are implemented across sectors, organizational models, and national contexts. Empirical studies in Europe show extensive deployment in logistics, healthcare, professional services, and public administration, while also indicating uneven exposure among workers depending on occupation, skill level, and regulatory environment. These analyses describe the emergence of hybrid workplaces in which algorithmic decision support operates alongside human oversight, as well as fully platformised environments where automated systems dominate task allocation, evaluation, and workflow coordination. Importantly, research demonstrates that algorithmic stressors such as pervasive digital monitoring, performance scoring, and lack of transparency are distributed unequally, with semi-skilled, low-skilled, and frontline occupations facing disproportionately high levels of anxiety, unpredictability, and perceived incomprehensibility (Gonzalez Vazquez et al., 2025; Cox, Oosterwijk, 2024; Rani et al., OECD, 2025; Keegan, Meijerink, 2025).

In parallel, a growing body of scholarship proposes frameworks for responsible algorithmic management aimed at mitigating these risks through transparency, explainability, auditability, and meaningful human oversight. Research shows that transparency-by-design solutions, explainable AI interfaces, and structured human-in-the-loop systems can reduce perceived unfairness, strengthen trust, and improve adaptation under uncertainty. Ethical and governance frameworks increasingly emphasise worker participation in system design, authenticity and control in algorithmic interactions, and institutional safeguards that maintain human agency in digitally mediated work settings. Empirical findings indicate that organizations implementing such safeguards—particularly through communicative clarity, participatory mechanisms, and oversight protocols—experience fewer negative psychological outcomes and greater resilience in decision-making under volatile conditions (Shin, 2021; Kritikos, Iphofen, 2024;

Papagiannidis et al., 2025; Rivera et al., 2025; European Parliament, 2025; Meijerink et al., 2021; Cui et al., 2024; OECD, 2025).

Finally, broader theoretical and normative contributions stress that algorithmic systems reshape not only managerial routines but also the moral and experiential dimensions of work. Analyses grounded in organizational ethics and social philosophy argue that excessive reliance on algorithmic metrics can weaken relational aspects of work, reduce opportunities for judgment, and undermine the cultivation of meaningful professional agency. These concerns highlight the need for leadership approaches that preserve human interpretation, contextual sensitivity, and shared sense-making in environments increasingly shaped by automated decision systems. Together, this literature shows that algorithmic management generates a fundamental paradox: while promising efficiency, precision, and control, it simultaneously risks producing the brittleness, anxiety, nonlinearity, and incomprehensibility that characterize the BANI world (García-Ruiz, Rocchi, 2025).

Building on the reviewed scholarship, it becomes evident that algorithmic management operates in diverse configurations across European workplaces, differing in their levels of autonomy, opacity, and behavioural rigidity. Existing conceptual and empirical studies illuminate how these systems may generate brittleness, anxiety and incomprehensibility, while simultaneously showing that responsible governance mechanisms - such as transparency, human oversight and participatory design - can mitigate these effects and support more human-centric leadership. Yet despite these advances, important questions remain regarding the scale and distribution of algorithmic management practices across occupations, sectors and national contexts, as well as their interaction with workers' experiences of the BANI conditions. These gaps create a clear need for comprehensive, comparative evidence capable of linking the theoretical vulnerabilities discussed in the literature with their observable manifestations in real-world workplaces. The subsequent Results section addresses this need by drawing on recent large-scale European analyses, including the AIM-WORK survey and OECD data, to quantify the prevalence and patterns of algorithmic management and to provide an empirical foundation for the research questions guiding this study (Gonzalez Vazquez et al., 2025; OECD, 2025).

3. Methods

This study employs a mixed-methods approach, combining a systematic literature review with secondary analysis of large-scale datasets to examine algorithmic management in BANI-affected workplaces. The aim is to investigate how algorithmic design features influence organizational brittleness, employee anxiety, and incomprehensibility, and how responsible practices may mitigate these effects.

The empirical analysis draws on the AIM-WORK survey (De Cuyper et al., 2025; Gonzalez Vazquez et al., 2025), which provides Europe-wide data on digital monitoring, algorithmic management, AI adoption, and platformisation across sectors and occupations, and the OECD report “Algorithmic Management in the Workplace” (OECD, 2025), offering cross-national statistics on adoption, system design, and organizational outcomes including autonomy, transparency, and human-in-the-loop mechanisms.

In parallel, a systematic review of publications from 2020-2025 synthesized conceptual and empirical work on algorithmic functions, impacts on employee well-being, and mitigation strategies. Descriptive statistics and cross-tabulations were used to analyze patterns of algorithmic management and associations with BANI-related vulnerabilities, while the literature review provided interpretive context and informed the discussion of potential mechanisms and practical implications. Given the secondary nature of the data, leadership is operationalized indirectly using organizational and work-design indicators available in the EU and OECD datasets—such as autonomy, participatory practices, communication clarity, perceived fairness, and human oversight—which collectively reflect conditions associated with adaptive and human-centric leadership under algorithmic management.

4. Results

This section presents empirical findings regarding the prevalence and characteristics of algorithmic management (AM) in European workplaces, focusing on their implications for organizational brittleness, anxiety, and incomprehensibility, as framed by the BANI model. Data from the AIM-WORK survey (De Cuyper et al., 2025; Gonzalez Vazquez et al., 2025) and OECD (2025) form the basis of the discussion, addressing RQ1 and H1 quantitatively, while conceptual insights related to RQ2/H2 and RQ3/H3 are elaborated qualitatively.

4.1. Prevalence and Types of Algorithmic Management

Algorithmic management is present in a substantial share of European workplaces, although its prevalence varies considerably across specific practices and national contexts. Figure 1 presents the average prevalence of eight forms of algorithmic management across the EU-27, as reported by workers.

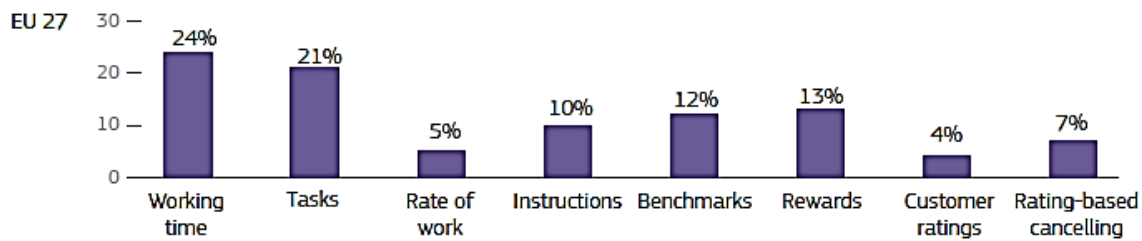


Figure 1. Prevalence of Algorithmic Management across EU countries.

Source: Gonzalez Vazquez, I., Fernandez Macias, E., Wright, S., Villani, D., 2025.

The most widespread form of algorithmic management is the automatic allocation of working time, such as rosters or shifts, affecting approximately 24% of EU workers. This is followed by the automatic allocation of work tasks, reported by around 21% of employees. These two practices represent the dominant modes through which algorithmic systems structure everyday work processes in European organizations. Other forms of algorithmic management are less prevalent. Automated systems of reward, including the assignment of points, prizes, or ratings, affect around 13% of workers, while automated benchmarking practices, such as performance rankings displayed in digital dashboards, are reported by 12%. Approximately 10% of employees receive automated instructions guiding the execution of their work tasks. More intensive and controlling practices are comparatively rare at the EU level. Automatic cancellation of shifts affects about 7% of workers, automatic determination of work speed 5%, and the use of online customer ratings only 4%. Although currently less widespread, these practices represent forms of algorithmic control with potentially strong implications for perceived autonomy, predictability, and emotional strain in the workplace.

Beyond these aggregate patterns, the data reveal substantial cross-national variation in the prevalence of algorithmic management. Higher levels of exposure are observed in countries such as Spain, Poland, Ireland, and Romania, where multiple forms of algorithmic management exceed the EU average. In contrast, lower prevalence is reported in countries including Greece, Bulgaria, Hungary, and the Netherlands. These differences illustrate the contextual embeddedness of algorithmic management and suggest that the same forms of technology may produce different levels of organizational brittleness and employee anxiety depending on the national and institutional environment.

Overall, these results indicate that algorithmic management in the EU is primarily concentrated in scheduling and task allocation functions, while more intensive forms of automated control remain less common. From the perspective of the BANI framework, widespread allocation of working time and tasks can contribute to brittleness by creating rigid structures, and increase worker anxiety through reduced discretion and predictability. These patterns directly inform RQ1 and support H1, indicating that higher exposure to algorithmic management is associated with potential vulnerabilities in employee well-being and organizational stability.

4.2. Adoption of AI Tools by Occupation

Figure 2 presents the use of AI-powered tools at work across eight occupational groups in the EU, based on AIM-WORK survey data. On average, roughly one-third of EU workers (29.9%) reported using an AI tool at least once in the past 12 months. This indicates a substantial uptake of AI in workplace tasks, despite the recent availability of many of these technologies.

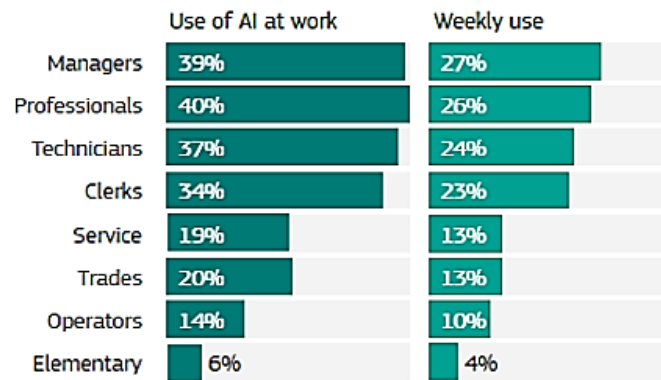


Figure 2. Adoption of AI Tools at Work by Occupation in the EU.

Source: Gonzalez Vazquez, I., Fernandez Macias, E., Wright, S., Villani, D., 2025.

Usage differs markedly by occupation. White-collar occupations—including managers, professionals, technicians, and clerks—show the highest levels of AI adoption, with more than one-third of workers in each group reporting use. In contrast, adoption is considerably lower among service, trades, and operator roles, affecting fewer than one-fifth of employees. Elementary occupations exhibit the lowest usage, with only 6% of workers reporting any engagement with AI tools. Frequency of use is also notable: approximately 20% of EU workers report using AI tools at least weekly in the course of their main job. Employees use AI tools for multiple purposes, most commonly writing and translation, with an average of three purposes per worker.

These occupation-specific patterns align with broader national-level variation observed in the EU. Countries such as Denmark, Belgium, the Netherlands, Finland, and Austria report AI adoption above or close to 40%, whereas Bulgaria, Romania, and Greece show lower adoption rates, below 20%. Overall, most EU Member States exhibit prevalence levels around or above the EU average, indicating widespread, though uneven, integration of AI tools across occupations and countries.

These disparities in AI adoption have important implications from the perspective of BANI. Lower exposure to AI tools among service, trades, operator, and elementary occupations may contribute to incomprehensibility and heightened anxiety, as employees have less opportunity to engage with or understand the systems shaping their work. Conversely, higher adoption in white-collar roles may reinforce efficiency but also introduce brittleness by centralizing decision-making around algorithmic systems. Thus, these results provide empirical support for RQ1 and H1, highlighting how uneven integration of AI and algorithmic tools contributes to

vulnerability patterns identified in the BANI framework. Moreover, they set the stage for examining broader patterns of platformisation, where multiple forms of algorithmic management combine to shape work organization across sectors and countries.

4.3. Platformisation Typology

Algorithmic management in European workplaces manifests in diverse configurations, which can be described along a six-level typology. At one end are workers not exposed to digital tools, followed by those who use digital tools but are not subject to algorithmic management or monitoring. The remaining four levels represent increasing exposure to platformisation: partial platformisation, where workers experience some combination of monitoring and algorithmic management; informational platformisation, combining activity monitoring with algorithmic evaluation; physical platformisation, involving physical monitoring alongside algorithmic direction; and full platformisation, in which employees are simultaneously exposed to all forms of monitoring and algorithmic management.

In the EU-27, 6% of workers are not exposed to digital tools, 33% use digital tools without algorithmic management, 42% fall under partial platformisation, 9% experience informational platformisation, 7% are subject to physical platformisation, and 2% are fully platformised.

Figure 3 presents the prevalence of platformisation of work by country, focusing on the four categories representing active exposure to algorithmic management: partial, informational, physical, and full platformisation. Workers without digital tools or using only digital tools without algorithmic management are not shown in the figure.

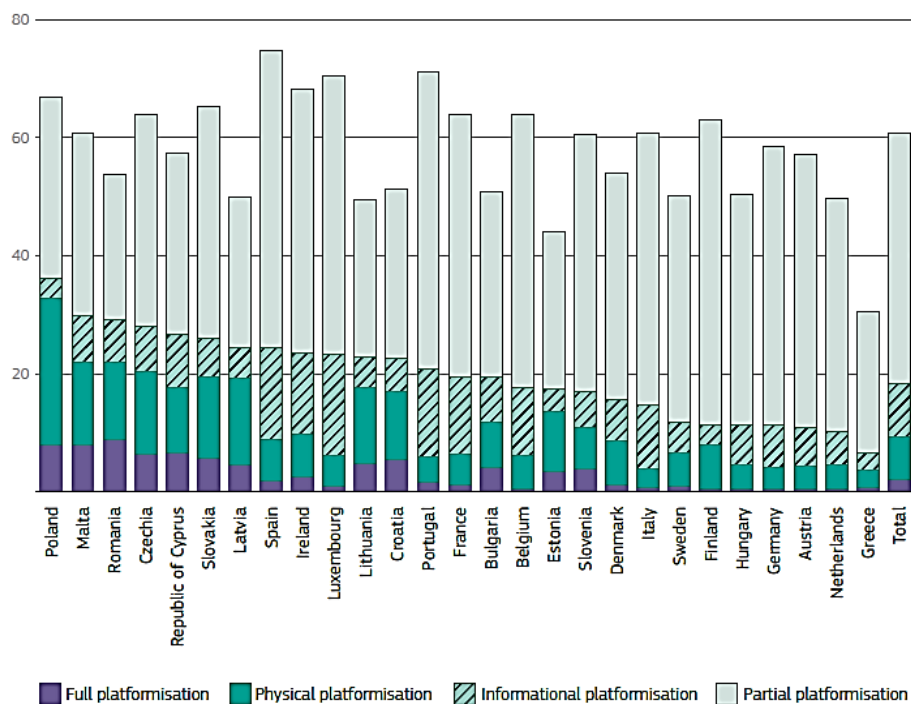


Figure 3. Prevalence of platformisation of work by country.

Source: Gonzalez Vazquez, I., Fernandez Macias, E., Wright, S., Villani, D., 2025.

Platformisation is particularly high in most Central and Eastern European Member States, with many countries showing percentages of workers in full platformisation between 5% and 10%, and in physical platformisation often above 10% (Poland exceeding 20%). In contrast, Continental and Northern European countries generally show low levels of active platformisation. Southern-Western Member States such as Spain, Portugal, France, Belgium, and Ireland display intermediate levels; however, in these countries, the higher overall platformisation is largely due to informational platformisation, which is considered less intrusive, while fully or physically platformised work remains relatively low. Partial platformisation does not follow a clear geographic pattern.

These patterns illustrate the diverse ways algorithmic and digital control is implemented across Europe, with full and physical platformisation being associated with higher stress levels and reduced autonomy. Overall, the prevalence and configuration of platformisation highlight how algorithmic systems contribute to nonlinear work experiences, reinforcing organizational brittleness and incomprehensibility, central to RQ1 and H1.

4.4. Cross-national and Sectoral Variations and Conceptual Implications

Complementary evidence from the OECD (2025) highlights substantial cross-national and sectoral variation in the adoption, design, and governance of algorithmic management systems. Across surveyed countries, firms report differing degrees of reliance on algorithmic tools for task allocation, performance monitoring, and decision support, as well as marked differences in how these systems affect employee autonomy, clarity of responsibility, and managerial satisfaction. These findings underscore the importance of contextual factors—such as institutional frameworks, sectoral characteristics, and organizational maturity—in shaping the outcomes of algorithmic management. Importantly, OECD data reveal that the effects of algorithmic management are closely linked to the presence or absence of governance mechanisms. Organizations that deploy algorithmic systems with limited transparency or minimal human oversight report higher levels of uncertainty regarding accountability, decision logic, and employee reactions. Such configurations are associated with heightened organizational anxiety and incomprehensibility, particularly in environments characterised by rapid change and complex decision-making, reflecting key dimensions of the BANI framework.

Conversely, firms that implement responsible algorithmic management practices—including human-in-the-loop (HITL) arrangements, transparency-by-design, explainability mechanisms, and formal oversight policies—report more positive outcomes. These organizations exhibit higher levels of employee trust, stronger perceptions of procedural fairness, and greater adaptive capacity in responding to unexpected events. From a BANI perspective, these governance features function as stabilising mechanisms: they reduce anxiety by clarifying expectations and decision rationales, mitigate incomprehensibility by making algorithmic processes more interpretable, and enhance resilience by preserving human judgement in non-linear or ambiguous situations. These findings provide empirical support for

RQ2 and H2, demonstrating that specific design features of algorithmic management systems play a critical role in mitigating BANI-related vulnerabilities. They also speak directly to RQ3 and H3, as responsible governance arrangements enable leaders to leverage algorithmic efficiency while maintaining relational coordination, empathy, and contextual sensitivity. Rather than replacing leadership, algorithmic systems governed in this way appear to reconfigure leadership roles toward interpretation, mediation, and sense-making—capabilities that are particularly vital in brittle and anxiety-prone organizational environments (OECD, 2025).

4.5. Interpretative Insights in the Context of BANI

The empirical evidence points to several patterns consistent with the BANI framework. The high prevalence of algorithmic management and platformization contributes to fragility by creating rigid, centralized decision-making structures. The uneven implementation of AI tools across professions contributes to misunderstandings and perceived inequalities. Scenarios of full and partial platformization illustrate nonlinear work experiences, where employees face varying levels of control and oversight, often difficult to predict. A conceptual analysis of governance mechanisms highlights the importance of transparency, integration of HITL, and oversight in reducing anxiety and misunderstandings and promoting adaptive, human-centered leadership.

The empirical evidence presented in this section reveals several patterns that closely align with the BANI framework and directly address the study's research questions. The widespread adoption of algorithmic management practices, particularly in scheduling and task allocation, contributes to organizational fragility by reinforcing rigid, centralized decision-making structures that are susceptible to disruption. The uneven implementation of AI tools across professions further contributes to misunderstandings and perceived inequalities, as workers experience significantly different levels of exposure, understanding, and control over algorithmic systems.

Patterns of full and partial platformization illustrate a distinct nonlinearity in work experiences, where workers encounter variable and often unpredictable combinations of algorithmic allocation, evaluation, and monitoring. These configurations generate feedback loops and disproportionate impacts on work intensity, autonomy, and supervision that are difficult to predict for both workers and managers. Finally, evidence on governance mechanisms suggests that transparency, human integration, and formal oversight play a crucial role in reducing anxiety and misunderstandings while fostering more adaptive and human-centered leadership practices in algorithmic workplaces.

5. Discussion

The results of this study illuminate the dual nature of algorithmic management (AM) in contemporary European workplaces, providing empirical evidence that complements existing conceptual and qualitative research. On one hand, algorithmic systems enable enhanced operational efficiency, predictive power, and workflow optimization, as shown by the prevalence of algorithmic time allocation, AI adoption, and platformization typologies observed in the AIM-WORK survey and OECD data (De Cuyper et al., 2025; Gonzalez Vazquez et al., 2025; OECD, 2025). On the other hand, these same systems generate BANI-related vulnerabilities, including organizational brittleness, heightened employee anxiety, and incomprehensibility of decision processes. The empirical patterns align with the literature, confirming that algorithmic autonomy, opacity, and rigidity are associated with increased fragility and reduced human interpretive capacity (Möhlmann et al., 2021; Parent-Rochelleau, Parker, 2022; Zayid et al., 2024).

The findings reveal that different configurations of algorithmic management produce varying levels of risk. Workplaces characterized by fully automated task allocation and opaque evaluation systems tend to concentrate stress and anxiety among employees, particularly in sectors and countries where oversight and human involvement are limited. Conversely, workplaces that integrate human-in-the-loop mechanisms, transparency-by-design, and explainable AI features show potential to mitigate these risks, enhancing trust, perceived fairness, and adaptive capacity (Benlian, 2022; Glikson, Woolley, 2021; OECD, 2025). These observations support H2, suggesting that design choices in algorithmic systems are critical in determining whether AM contributes to resilience or exacerbates BANI vulnerabilities.

Sectoral and occupational variations also emerge as significant. Highly skilled and white-collar employees exhibit greater exposure to AI tools and algorithmic evaluation, yet they also benefit more from interpretive and decision-making flexibility, while semi-skilled and elementary occupations face reduced agency and higher vulnerability to anxiety and incomprehensibility (Gonzalez Vazquez et al., 2025; Fernández-Macias et al., 2025; Kinowska et al., 2023). These findings underscore the nonlinearity of algorithmic impacts across hierarchical and educational strata, illustrating how AM can simultaneously empower and constrain employees in ways that are context-dependent.

Importantly, the results suggest that responsible algorithmic management (RAM) practices are central to reconciling efficiency with human-centric leadership. The integration of HITL checkpoints, participatory design, and transparent audit mechanisms enables leaders to leverage algorithmic insights without compromising relational and ethical judgment, supporting adaptive and empathetic decision-making (OECD, 2025; Europarl, 2025; Benlian, 2022; Papagiannidis, 2025). In this sense, algorithmic systems, when coupled with RAM,

can transform potential sources of brittleness and anxiety into instruments of organizational adaptability and resilience.

Several limitations should be acknowledged. The study relies on secondary, cross-sectional datasets (AIM-WORK and OECD), which limits causal inference. Occupational and national differences are only partly captured, as cultural and regulatory contexts may shape the effects of algorithmic management. Leadership and employee well-being are measured indirectly through organizational indicators rather than direct assessments. In addition, some evidence on HITL and transparency practices is case-based, and rapid developments in AI may outpace the existing literature. Despite these limitations, the study provides a solid foundation for analyzing the dual effects of algorithmic management on efficiency and human-centric leadership.

These limitations also point to opportunities for future research. Building on this, studies could track employee experiences, leadership practices, and organizational resilience in workplaces affected by algorithmic management, combining quantitative surveys with qualitative interviews to capture both measurable outcomes (e.g., employee anxiety, autonomy) and contextual insights into leadership behaviors. A possible research project might involve a cross-national panel of organizations implementing varying configurations of HITL, transparency, and algorithmic autonomy, allowing for causal analysis of how responsible algorithmic management shapes adaptive, human-centric leadership. Such research would directly address the gaps highlighted in our review and secondary data analysis, providing stronger empirical foundations for understanding the interplay between algorithmic efficiency and human-centered organizational practices.

6. Conclusion

This study demonstrates that algorithmic management embodies a paradox in organizational contexts affected by BANI. While algorithmic management increases operational efficiency and enables rapid, data-driven decision-making, it also carries the potential to generate fragility, employee anxiety, and misunderstanding if systems are too opaque or rigid. Empirical evidence from the AIM-WORK study and OECD analyses confirms these dual effects across professions, sectors, and European countries, supporting the conceptual arguments presented in the literature.

The findings highlight the crucial role of responsible algorithmic management in mitigating these risks. Practices such as transparency in design, explainable AI, HITL integration, participatory design, and adaptive leadership enable organizations to leverage algorithmic efficiency while maintaining human agency, trust, and relational coordination. RAM emerges as a key path to transforming algorithmic systems from potential sources of fragility into tools for resilience and adaptive advantage.

From a theoretical perspective, this research expands our understanding of the BANI paradox in contemporary workplaces by linking algorithmic configurations to specific vulnerabilities and identifying design features that mitigate these effects. In practice, the study provides practical guidance for managers and policymakers, emphasizing the need for algorithmic transparency, meaningful human oversight, and leadership development aligned with empathy, adaptability, and ethical decision-making.

Overall, by integrating algorithmic efficiency with human-centered management, organizations can navigate the challenges of the BANI world, achieving both technological optimization and sustainable employee well-being.

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POLISH YOUNG ONLINE SHOPPERS' EXPERIENCES WITH ECOLOGICAL E-COMMERCE

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Purpose: As in many economies, greening is entering e-commerce as an expression of the desire for sustainability. The aim of the study has been to diagnose the attitudes towards green e-commerce of young people, who often self-identify or are perceived to be green. The attributes of eco e-commerce were identified for the study. The research problem, which was formulated in the form of a question as to whether ecological e-commerce has become widespread on both the demand and supply sides.

Design/methodology/approach: In this paper, a qualitative study has been used, and a consumer survey was conducted that explored what the greening of e-commerce looks like. Results of selected statistical analyses were also presented.

Findings: The results of the study confirmed that, among both sellers and young online shoppers, ecological practices are not marginal but very much present. Young consumers identify with the slow life or less mess lifestyles and show a lot of pro-environmental behavior both in everyday life and in online shopping; but the pro-environmental aspect is not the main motive for online shopping.

Research limitations/implications A limitation of the statistical study was the large number of questions containing matrix-based responses. This resulted in blurred correlations. The questions concerned the pro-ecological attitudes of e-consumers themselves, not only in online shopping but also in everyday life, and assessed the greening of e-commerce by sellers.

Practical implications: The article can be used for application purposes, since it points out what e-sellers can improve as far as the greening of e-commerce is concerned. In summary, it can be concluded that the greening of e-commerce is not a temporary trend, but a well-advanced process.

Social implications It can be educational for society, as it provides a set of best practices in e-commerce. Familiarizing society with these practices will help increase social responsibility for the environment.

Originality/value: This article defines the attributes of e-commerce from both a demand and supply perspective, which can serve as a model for ecological e-commerce.

Keywords: e-commerce, green e-commerce, eco e-sellers, eco e-customers.

Category of the paper: Research paper.

1. Introduction

After almost four decades of development, e-commerce has become widespread. As global internet access and adoption rapidly increase, with over five billion internet users worldwide, the number of people making purchases online is ever-increasing. In 2024, retail e-commerce sales are estimated to exceed 6.3 trillion U.S. dollars worldwide, and this figure is expected to reach new heights in the coming years (Statista, 2024). Poland is among the countries where e-commerce has gained popularity. About 64% of 16-74 year olds shop online (Trade News, 2023). Buyers account for about 79% of internet users, i.e. people who use the internet regularly (every day or almost every day).

Not only does e-commerce contribute to growth, but also to socio-economic development. At the same time, this development should be sustainable. Thus, supporting sustainable e-commerce is becoming a challenge since this requires an increase in ecological awareness among all stakeholders. The issues of the greening of economic processes have been raised by decision-makers for many years, so it is inevitable that they will also be introduced in the area of contemporary forms of trade. The attitudes and actions of the younger generation are particularly important (Green Generation Report, 2020; WCO, 2022). This issue is of interest to the authors, who have conducted empirical research among Polish youth.

The conceptualization of ecological e-commerce (EEC) requires an analysis of the evolution of commercial activities. This evolution from traditional commerce, through electronic commerce to increasingly ecological electronic commerce, has been the result of phenomena and processes occurring in the socio-economic space (Nanehkaran, 2013). It made the world interconnected (Ferrera, Kessedjian, 2019), and is improving the quality of life (Wolf, 2023; Pieczywok, 2023; Mohdhar, Shaalan, 2021). Dynamic advances in technology and increasing globalization, trade liberalization, deregulation, migration, and the expansion of capitalism have led to the growth of e-commerce (López González, Jouan, 2017; Aydına, Savrul, 2014; Totonchi, Kakamanshadi, 2011; Wodnicka, Skurpel, 2011). Therefore, transportation and logistical issues (Mangiaracina et al., 2015; Sallnäs, Björklund, 2023), including the impact of last mile (Vakulenko et al., 2019), have been identified as particularly important in the development of e-commerce.

Online trade is developing, but here too, the need for sustainable development is being noticed - that is, one in which economic growth and social progress are achieved, but with respect for the natural environment (Hossain et al., 2022; Meherishi et al., 2019; Kawa, 2023). Eco-conscious electronic commerce has been called ecological e-commerce, green e-commerce and sustainable e-commerce. In the context of sustainability, numerous research studies have been devoted to reducing the carbon footprint caused by manufacturing, trading and waste management activities (Groening et al., 2015; Abukhader, 2008; WCO, 2022). Prasertwit et al.,

(2023) when conceptualizing EEC, present a process that includes five stages from material receiving to disposal (Figure 1).



Figure 1. E-commerce green process.

Source: Prasertwit, Kanchanasuntorn, Vongmanee, 2023.

Fichter (2008) identifies three main categories of environmental effects of e-commerce such as : ITC infrastructure; transformation of markets, subsequent and rebound effects.

According to Sarkar (2023), the key aspects of environmentally friendly e-commerce are the following:

- Reducing the need for distribution centres to store products close to retail outlets, which saves energy in warehouses.
- The promotion process should have an open and long-term perspective, thereby highlighting environmental sustainability and social acceptability.
- A new, complete and mutually dependent viewpoint of the correlation between the market, culture, environment, and economy.
- Awareness of the impact of e-vehicles on last mile delivery for zero-emission fleets.
- Creating environmental sensitivity and drawing attention to recycling and paper for packaging for environmental sustainability.
- Building awareness among consumers about local delivery from local e-retail shops in order to minimize carbon emissions.

EEC can be conceptualized from a market perspective. In this case, it is buyers and sellers using the e-commerce platform who are the key actors in the real sphere of the market (Deeter-Schmelz, Kennedy, 2004). It is primarily their attitudes and actions that influence the greening of e-commerce. In addition, two important stakeholders, such as companies in the transportation and logistical sectors and companies in the financial sector, should be identified in the process of greening.

2. Customers and ecological online shopping

A number of studies have been devoted to e-commerce customers. When shopping online, shoppers pay attention to elements such as: product value, product characteristics, information quality, site features, website design, quality of services offered through the website, quality of communication, delivery time, forms of payment, risk and privacy of online shopping,

post-purchase quality, merchandise attributes, and the goodwill of the country of origin (Hajli, 2014; Hoque et al., 2015; Fedorko et al., 2018; Vegiayan et al., 2013).

When analyzing the market from the buyer's perspective, it is important to note that the buyer has limited influence on the development of ECCs. However, the buyer can make important ECC-related decisions, including those regarding the choice of product, seller, platform, delivery method and payment method. He has less influence on the choice of packaging, transport company and financial institution. E-commerce uses cashless transfers carried out in virtual space. These are considered more ecological than cash transactions (Slozko, Pelo, 2014; Wu et al., 2023; Bhavsar, Samanta, 2022). A customer shopping online usually has several payment methods to choose from e.g. bank transfer, a specific method of contactless payment – known in Poland as Blik, debit or credit card payment. Research in China has shown that most customers choose credit cards (Liu et al., 2008) but the authors of the presented study were not aware of any studies that indicate which of these forms is the most ecological. It can be assumed that there is little difference between them in terms of negative environmental impact.

Many researchers believe that buyers are paying increasing attention to the ecological aspects of e-commerce (Łysoń, 2023). A survey of 2,000 consumers in Poland (Together for Earth Report, 2020), shows that only 24% (and 14% among the youngest respondents) do not perceive any ecologically unfriendly behavior of sellers when shopping online. The rest considered as harmful the following:

- the use of foil to package parcels (20%),
- wrapping food products in plastic bags and shopping bags (19%),
- packing small products in oversized parcels with fillers (18%),
- sending products from the same place in batches (16%),

lack of possibility to pick up a parcel at a dedicated point, e.g. a parcel machine (14%). Views are emerging (Jagoda et al., 2023) that the identification of factors for choosing a delivery method and factors that motivate e-customers to choose an eco-friendly delivery method is still unrecognized. There is some optimism in the research (Villa et al., 2022), which shows that the majority of customers (70.25%) are willing to pay more for eco-friendly delivery and accept delayed delivery if they support sustainable development. Other researchers seem to be more realistic and argue that for many customers, delivery time is the priority and in this case ecological issues become less important (Rahman et al. 2018). The development of eco e-commerce requires educational initiatives in both the real and regulatory spheres (Surmacz, 2014; Olejniczak et al., 2023). It is believed that all stakeholders, including the government, retailers and consumers should apply policies governing sustainable e-commerce (Kwiliński, 2023; Oláh et al., 2023).

Interestingly, the trend towards ecology in everyday life is becoming increasingly fashionable. Living in the spirit of zero waste, slow life, and less mess is an attribute of the new times. Young people are especially becoming adherents of such attitudes or ideologies

(Villa et al., 2022 and also Together for the Earth Report, 2020). Thus there is hope in them that public expectations and pressure will increase for e-commerce to be developed more and more in harmony with the natural environment.

3. Green e-commerce model

In ecological (green) e-commerce, responsibility lies with all parties to a transaction. In this paper, the focus will be on the main participants in online transactions: buyers and sellers. The following attributes of eco e-commerce, both on the buyers' and the sellers' side, were collected on the basis of good practices, e.g. courier delivery providers (DHL, InPost, UPS and others) and the proposed directions of development of e-commerce (i.e. Sallnäs, Björklund, 2023). It may constitute the eco e-commerce model postulated by the authors and is:

- conceptual (result of a literature review),
- normative (postulates, good practices),
- not yet fully empirically grounded.

Ecological sellers, in order to be recognized as eco sellers, should implement the following attributes when selling online:

1. Offering eco-friendly goods in the online store - obviously not all goods for sale are ecological, but the seller has a choice of what to sell.
2. Offering a reduced price for products that are close to their expiry date, have minor aesthetic defects or have been returned by customers - this measure aims at minimizing waste. Rather than throwing them away, the price should be reduced to sell the goods before they are worthless.
3. Providing product description and graphics as detailed as possible on the e-store website in order to limit returns to a minimum - if the customer can thoroughly familiarize himself with all the parameters and characteristics of the product, and watch it on well-visualized photos/videos, the purchase will surely prove successful.
4. Using incentives by the seller to make larger purchases at one time - one shipment instead of several.
5. Retailers offering ecological delivery e.g. personal collection, parcel or pick-up points, cumulative shipments (sending several parcels as one).
6. The use of ecological packaging by the seller, e.g. cardboard boxes, biodegradable packaging, reusable packaging, recycled packaging, as well as packaging made from natural materials - instead of plastic packaging.
7. Adjusting the size of the packaging by the seller to the size of the goods being purchased, thereby reducing the material required for packaging and saving space in transport.

8. The use of ecological fillers for empty spaces in the package, which protect the contents e.g.: recycled cardboard boxes, paper/cardboard fillers, shredder cuttings, biodegradable polymer/plant "crisps" e.g. "skropak" (a filling resembling cylinders or dumplings in shape) - instead of foil, e.g. bubble wrap, foam or polystyrene. However, in case recycled fillers are used, not too many of them should be used, so as not to litter the customer with your own waste and put the burden of disposal on the customer.
9. The use of digital sales documentation - e-mailed e-invoices instead of paper ones.
10. The use of electronic forms for returns, exchanges, cancellations instead of paper forms, all available from the seller's website.
11. The possibility of reserving a product in a retailer's store in order to try it on - which can minimize returns.
12. Collection of used products by stores in exchange for discounts, coupons, which can prevent improper disposal of products.
13. Offering a reduced original price by the retailer in exchange for a non-returnable purchase in order to limit returns. This, however, carries with it a waiver of the customer's statutory right to terminate the contract.
14. Having bicycle couriers deliver orders from local stores in order to use an environmentally friendly form of transport.

The above-mentioned postulated attributes of ecological sellers are those that can be identified and assessed by customers. In addition to these, one could also mention the use of ecological means of transport (e.g. electric or hybrid cars) by retailers or intermediaries (e.g. delivery companies), or the use of ecological own collection points - e.g. solar-powered parcel machines or pro-ecological waste management. However, these aspects are often unnoticeable to the final recipient, i.e. the customer, and will therefore be omitted from the survey.

Customers, meanwhile, should meet the following requirements in order to call themselves ecological:

1. Buying ecological and natural products online, maybe not exclusively, but they should be included in their purchases.
2. Thinking carefully about the need to buy a particular item, whether or not it is really necessary.
3. Limiting impulse purchases (e.g. under the influence of online advertising) in order not to buy things you may not need.
4. Buying used products on special platforms - e.g. on Vinted, OLX or Allegro, since there you can buy cheaper what is still in good condition.
5. Selling second-hand products on special platforms - e.g. on Vinted, OLX or Allegro to give them a second life.
6. Making larger online purchases at a time, supplied in one delivery.

7. Choosing eco-friendly delivery, e.g.: personally collected parcel or pick-up points, cumulative shipments (several shipments sent as one).
8. Paying a surcharge for eco-friendly packaging if requested by the seller.
9. Reusing the shipment packaging (e.g. for return delivery, another shipment or, for example, for storing things).
10. Disposing of product packaging and delivery packaging according to waste segregation rules.
11. Minimizing the delivery of returns.
12. Making returns, if they actually occur, in the packaging received from the seller.
13. In the case of self-packaging of returns, opting for ecological packaging.

In order to test the customer's credibility as an ecological customer, it would be worth checking whether or not he follows the principles of any pro-environmental ideas, for example - zero waste, less mess, slow life or if perhaps he is eco-friendly in every way. Ecological shopping should also be supported by pro-environmental actions in everyday life, such as:

- not throwing food away,
- saving water,
- saving energy,
- reducing the use of plastic,
- separating rubbish thoroughly,
- using cosmetics/chemicals which have not been tested on animals,
- using public transport/bicycle/scooter instead of a car,
- repairing things instead of throwing them away.

The above outlined attributes of ecological e-commerce will form the core of a survey study of young customers, who are more likely than others to declare eco-friendly attitudes.

4. Research methodology

The main theoretical objective was to conceptualize and identify the attributes of ecological e-commerce. The aim of the empirical research, in turn, was to diagnose young people's attitudes towards ecological e-commerce. To achieve the empirical objective, the following research questions were posed:

1. What is the respondents' attitude towards e-commerce - how often do they make purchases?
2. Are ecological aspects taken into account by buyers during online shopping?
3. Is what they buy ecological?
4. What ecological attitudes do respondents display in their lives?

5. How important are the various aspects of eco e-commerce to them?
6. Do they perceive eco aspects in e-commerce?

The main research problem was formulated in the form of a question: Has ecological e-commerce become widespread on both the demand and supply sides? In the context of the research objectives and questions, the following research hypotheses were formulated:

H1: Young customers display pro-ecological attitudes in e-commerce.

H2: The supply side (sellers) generally implement the concept of ecological e-commerce.

In order to meet the objectives and verify the hypotheses, a survey study was chosen, which is one of the most popular research methods suitable for obtaining customer opinions. An e-survey technique was used with a survey questionnaire.

It was decided to survey young people, who, according to other studies, are displaying highly pro-ecological attitudes. For the sake of convenience, the survey was conducted among Polish e-customers, which is a deliberate measure, as pro-ecological attitudes may differ from one nationality to another (Villa et al., 2022). Young people were arbitrarily considered to be between the ages of 18 and 29 years inclusive. The age limit was set so that those surveyed were of working age, i.e. able to make purchases based on their own financial means. It was planned to survey a minimum of 100 people, and the sampling was done using a non-randomized method. The population in the surveyed age range is not distinguished in detail in Polish demographic statistics (working age is defined, amongst others, in the range of 18-44 years, with no breakdown into detailed segments). Therefore, there is no sampling frame from which a quota sample could be drawn. The present sample is therefore a quasi-sample, but this does not undermine the validity of the study.

Individuals under 30 years of age on e-commerce-related social media sites were invited to participate in the survey, this may be considered a targeted selection, although people willing to participate were recruited.

In the survey questionnaire, use was made of questions to meet the stated objectives - the questions referred to the frequency of online shopping, the motives for online shopping and environmental attitudes in daily life. Likert, nominal, interval and ordinal (balanced) scales were used. One of the questions involved an assessment of the frequency with which the shoppers encountered displays of pro-ecological behavior on the part of sellers.

5. Results

5.1. Consumer survey results

Basic profile of respondents are presented in table 1. One hundred people took part in the survey, including 57% women. People with a financial status similar to their peers predominated (69%). Among the survey respondents, the largest group were those who shopped several times a week. They represented 65%. The respondents most often paid by Blik (contactless payments) (68%) and collected the ordered goods from a parcel machine (80%).

Table 1.
Basic profile of the respondents

Purchase frequency	Sex	Age in years
Several times a week - 9%.	Woman - 57%.	18-20 - 37%.
Several times a month - 65%.	Man - 42%.	21-23 - 35%.
Several times a year - 23%.	Other - 1%.	24-26 - 10%.
Once a year or less frequently - 3%.		27-29 - 19%.
Financial status	Method of payment	Preferred place of delivery
Lower than peer status - 11%.	By bank transfer - 13%.	Home/Work - 15%.
Close to peer status - 69%.	By credit /debit card - 11%.	A parcel machine - 80%.
Higher than peer status - 20%.	Contactless payment - 68%.	A post office - 1%.
	Cash on delivery - 6%.	Another collection point (for example a store) - 4%.
	Other - 3%.	

Source: Authors' own survey.

Respondents were asked how important various aspects of e-commerce were to them. The results are illustrated in Figure 2.

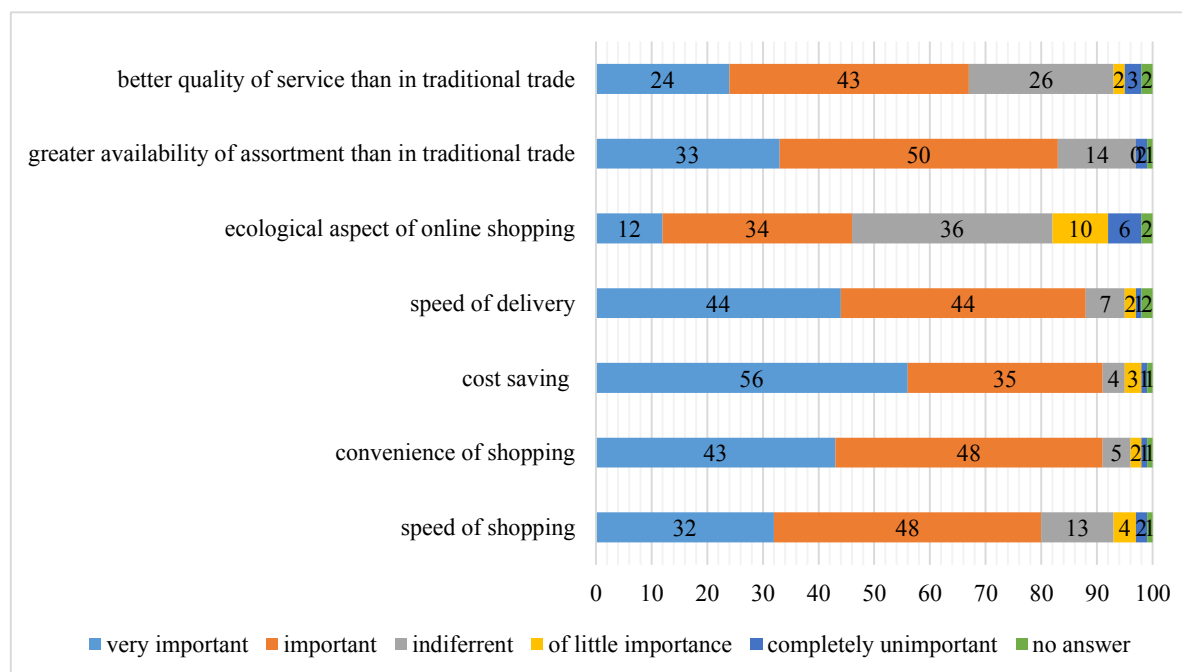


Figure 2. Importance of selected aspects of e-commerce (in %).

Source: Authors' own survey.

The following aspects of e-commerce are very important or important: cost savings and convenience of shopping (a total of 91% of indications for each), speed of delivery (for 88% of respondents) and greater availability of assortment than in traditional stores (for 83% of respondents). The ecological aspects of e-commerce are important or very important for only 46%, which is less than half of the respondents. Ecology in e-commerce was of least importance to respondents, and thus it may well be that ecological attitudes are only declarative.

Subsequent questions examined in more detail the customers' pro-ecological attitudes and values in this regard. Respondents were asked to declare which attitude was closest to them - from a totally eco-friendly person to one not guided by ecology at all in their life. The results are shown in Figure 3.

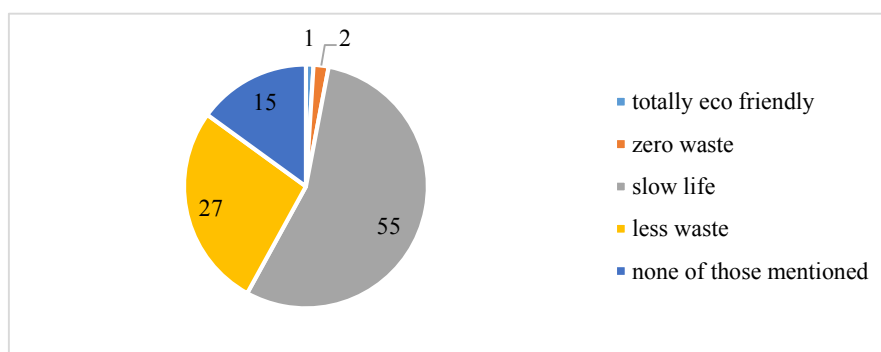


Figure 3. Professed pro-ecological attitudes (in %).

Source: Authors' own survey.

It turned out that the highest number of people (55%) identified themselves as adherents of the “slow life” ideology, that is to say, buying sensibly, fewer but better fitting things. Second in the group (27%) were followers of the “less waste” lifestyle. Only 1% of the respondents described themselves as eco in every way and 2% declared that they live in the spirit of zero waste. A sizable group of respondents (15%) did not identify themselves with either attitude. The results indicate that the respondents do not necessarily give priority to ecology, and they do not live as people determined to be pro-ecological. People identifying with a “slow life” and “less waste” lifestyle predominate in the group; however their ecological behavior can be considered as moderate. What is positive is that it occurs at least to this extent.

The frequency of pro-ecological behavior in the daily lives of the young people surveyed was also checked. As it turns out, pro-ecological behavior occurs in their lives always, very often or often (Figure 4). The results are encouraging.

As many as 85% of respondents indicated that they do not throw away food (at least they often do not do so). 83% of respondents save water. 82% strive to carefully sort their rubbish. It is encouraging that as many as 79% of the respondents declare that they repair things instead of throwing them away. More than three-quarters of the respondents save electricity. Furthermore, 72% often/very often or always use cosmetics or chemicals not tested on animals. 68 % declare a high frequency of using public transport, bicycle, scooter etc. instead of a car.

Also, two-thirds of those surveyed reduce their plastic consumption. Well above two-thirds of the people surveyed declare pro-ecological behavior in their daily life.

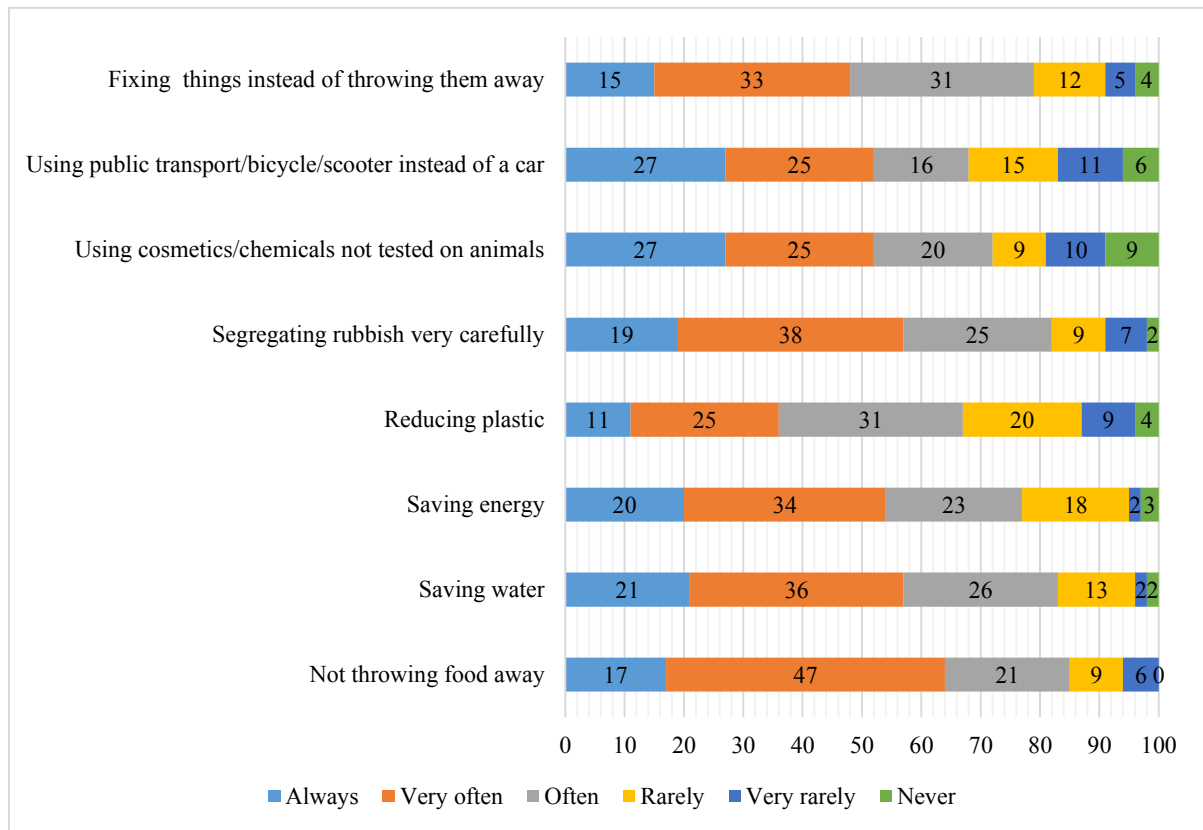


Figure 4. Pro-ecological behavior of respondents in everyday life (in %).

Source: Authors' own survey.

Therefore, respondents were also asked to what extent they were ecological when making online purchases (Figure 5).

The most common pro-ecological behavior displayed by online buyers was choosing ecological delivery - as many as 87% of the respondents choose it often, very often or always. As many as 83% of the respondents send returns in the packaging received from the retailer at least often. 82% of respondents dispose of product and delivery packaging according to the principles of waste segregation. The need for buying online is taken into account - at least often - by 79% of respondents, which partly confirms the idea of slow life declared by respondents. Eco or natural products are purchased at least often by 46% of the respondents, which can be considered a satisfactory result, since the respondents did not declare themselves to be radically ecological. About 50-60% of respondents sell or buy on platforms with second-hand goods at least often. And this is also an optimistic percentage. Yet, a sizable group of respondents is at least often tempted to buy online under the influence of advertising - which 46% of the respondents admitted doing.

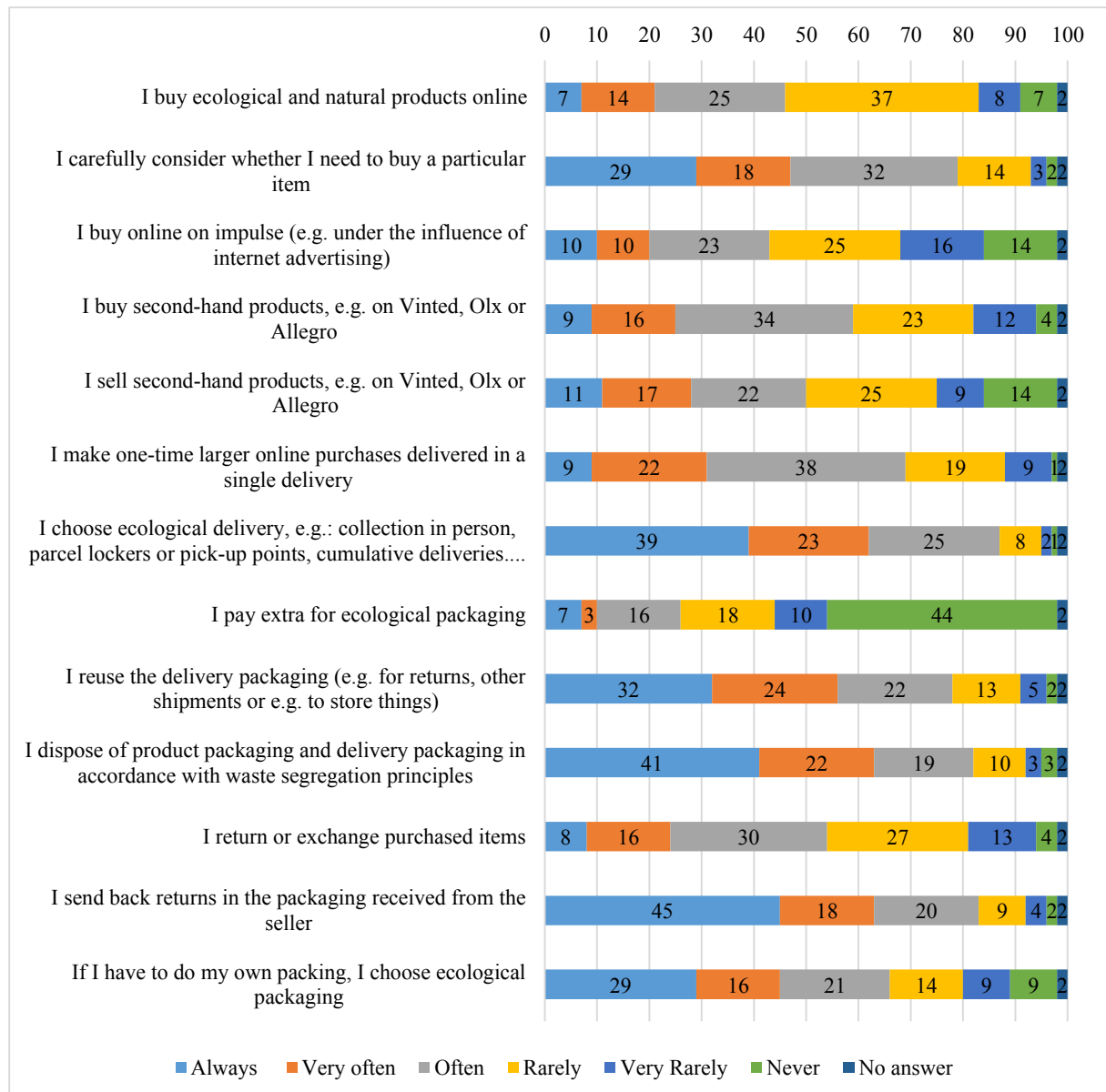


Figure 5. Pro-ecological activities of the respondents in online shopping (in %).

Source: Authors' own survey.

Unfortunately, also a sizable group returns products at least often, which does not support the idea of “slow life”. It might be that the purchases are not fully thought through, although the need to return might be due to a mismatch between the offer and the buyers' expectations. Finally, only one in four people declared that they at least often pay extra for ecological packaging, whereas the rest do not. What is puzzling here is whether the respondents actually paid for ecological delivery because it was an option to choose from, or whether they were aware that, in fact, the buyers pay for the packaging because the sellers somehow try to pass this cost on to the buyers. Also in this context, respondents were asked how much they would be willing to pay extra so that the packaging would be eco.

As it turns out, the majority of respondents (56%) would not want to pay a surcharge for ecological packaging at all. As many as 28% of them declared that they could pay a minimum charge of up to 2 PLN. For 15% the maximum charge could be 5 PLN, and only 1% of respondents (one person) declared that they might pay even 10 PLN. This means that respondents feel that the cost of ecological packaging should be borne by the seller, since the latter probably passes this cost on to the buyer anyway. It may also mean that they expect such packaging as standard.

Respondents also provided feedback on how often they encounter practices of e-commerce greening by sellers (Figure 6).

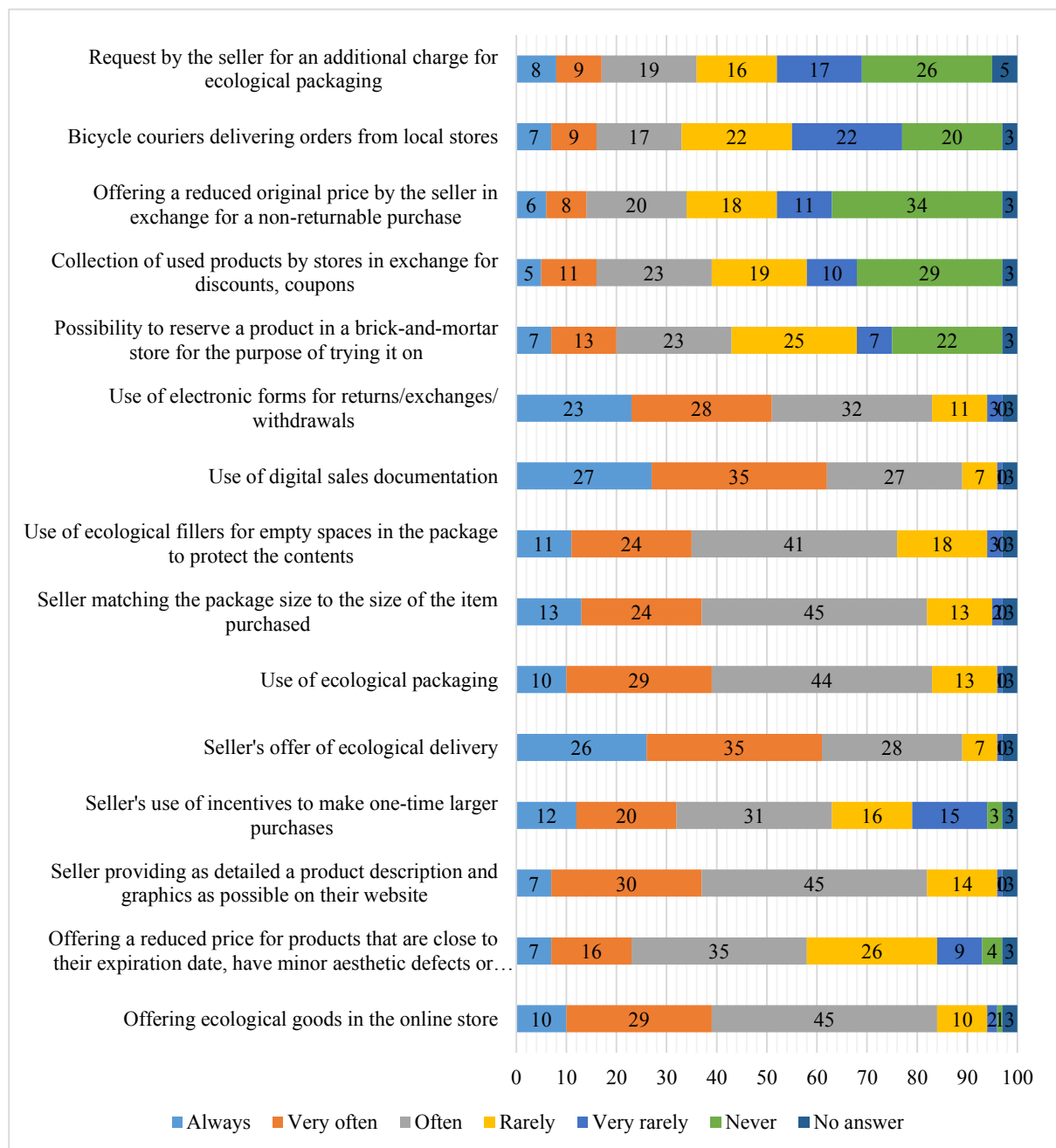


Figure 6. Frequency of pro-ecological activities of e-sellers in the opinion of respondents (in %).

Source: Authors' own survey.

Most frequently, customers have encountered e-sellers offering ecological delivery (e.g. parcel machines, in-person collection) - with as many as 89% encountering this often, very often or always. The same percentage of respondents have noticed the use of e-invoices and e-billing by e-sellers at least frequently. Also, as many as 84% of respondents have noticed, at least frequently, products that can be described as ecological or natural on offer. A similar proportion of respondents (82-83% each) have at least frequently encountered eco-packaging, the matching of package size to content size, electronic forms for return or withdrawal and the use of increasingly accurate product descriptions and visualizations via sellers' websites, which can lead to a reduction in the number of unsuccessful purchases. In the responses discussed, indications of very often and often predominated, which means that these solutions are quite common, but not yet radical and occurring every time.

More than three-quarters of the respondents noticed the use of ecological package fillers at least often. Some 63% of respondents noticed encouragement from sellers to make larger purchases - at least often - most likely by way of promotional activities. And 58% of the respondents noticed, at least often, price reductions on defective goods, goods after return, items perhaps damaged or with an approaching use-by date. About 30-40% of respondents also indicated that they encountered products being reserved for in-store fitting, collection of used products in exchange for discounts, additional fees being demanded for ecological packaging, reduced prices being offered for non-returnable purchases or bicycle couriers - all of which tend to be the least frequently encountered practices. It is therefore worth noting the frequency of the *never* responses, which ranged as high as 20-34%.

The final matter about which the respondents were asked was whether they had ever been asked by sellers about ecological aspects when expressing their opinion on online shopping. It was definitely noticeable that even sellers did not particularly raise ecological aspects when asking customers for their opinion on online shopping. Only 27 % were asked about this issue at least frequently, thus as many as 73 % were asked occasionally - while 18 % answered: *never*, and 34 % stated that the issue had rarely been the subject on which their opinion was surveyed. The result is puzzling. Why, then, are sellers not particularly emphasizing their pro-ecological attitudes? Is this of no interest to them since they do not consider it important? Or, on the contrary, do they see it as a necessary practice to introduce pro-ecological measures, but do not count on any applause in this matter? Maybe they do not see pro-ecological practices as a potential source of competitive advantage? These questions remain unanswered for the time being, but the doubts raised by the results presented here prompt the need for further research in this area in the future.

5.2. Results of selected statistical analyses

The responses were analyzed also for co-occurrence. For this purpose, correlation was examined using Spearman's coefficient. Correlation coefficients were assumed to be significant with a probability of $p < 0.05$. Key findings from the selected analyses:

1. The more pro-ecological the respondents' attitudes, the more (table 2):
 - a) they considered the necessity of online purchases more carefully,
 - b) they made fewer impulse purchases,
 - c) they were more meticulous in sorting product packaging and deliveries.
2. The more frequently respondents shopped, the more carefully they considered the necessity of purchasing ($R = 0.32$).
3. Although the survey sampled young e-consumers, they made less impulsive purchases with age ($R = -0.27$).
4. It also turned out that the younger the respondents, the more often they bought used items on websites like Vinted or OLX ($R = -0.22$).

Table 2.*Correlation matrix - selected results*

Pro-Environmental Attitudes in E-Commerce and Respondents' Pro-Environmental Attitudes	Spearman Correlation Coefficient (R)
I carefully consider the necessity of purchasing a given item	0.29
I buy online on impulse (e.g., influenced by online advertising)	-0.31
I throw away product packaging and shipping containers in accordance with waste separation guidelines	0.22

Source: Authors' own elaborations.

To exam the statistical significance of the obtained results, a nonparametric chi-square test was conducted, assuming a significance level of $\alpha = 0.05$. In particular, pro-environmental behavior in e-commerce was analyzed based on the respondents' gender. Key results:

- a) The chi-square test statistic for independence was 11.67 (significance $\alpha = 0.04$), demonstrating a relationship between gender and the frequency of choosing eco-friendly delivery. Women were more likely to choose eco-friendly delivery than men.
- b) The chi-square test statistic for independence was 11.19 (significance $\alpha = 0.048$), demonstrating a relationship between gender and the separation of product packaging waste or delivery. Women were more likely to separate waste than men.
- c) It was also found that gender was unrelated to such pro-environmental behaviors in e-shopping as: buying eco-friendly products, buying or selling used products on platforms such as Vinted or OLX, making larger one-time e-purchases, paying extra for eco-friendly delivery, eco-friendly packaging of returns, or reusing packaging. However, there was also no association between gender and impulsive shopping or returns, which are stereotypically considered feminine traits. There was also no association between gender and careful consideration of the need to make a purchase, which is typically the domain of men. In this regard, the lack of association is a somewhat surprising result.

The analysis showed that more pro-ecological attitudes of e-consumers are associated with more conscious purchasing decisions. At the same time, no relationship between gender and many other pro-ecological or impulsive purchasing behaviors was found, which is in contrast to established consumer stereotypes and may constitute a certain finding in this research.

6. Conclusions and Discussion

The analysis carried out made it possible to solve the research problem and answer the question of whether ecological e-commerce has become widespread on both the demand side and the supply side. It is worth noting that a specific group of customers was chosen as the demand side, namely young people, from 18 to 29 years old. As a result of the survey, one may conclude that, among both sellers and young online buyers, pro-ecological practices are very common and, most importantly, are not marginal.

The survey provided answers to the supporting questions that were formulated to specify the research problem:

- 1) Here it was found that ecological aspects in e-commerce were also considered, but they were much less important to customers than other e-commerce attributes. The pro-ecological aspect was not the main motive for shopping online.
- 2) It appears that buyers frequently purchased ecological or natural products. Almost half of the surveyed respondents bought them at least often. This means that customers are able to differentiate products based on the ecological aspect and, most importantly, they buy them quite consciously.
- 3) It turned out that respondents identify with the ideology of “slow life”, that is, buying sensibly, fewer but better-fitting things, as well as the “less waste” lifestyle - meaning less waste. There were few radical ecological customers; the dominant attitude, though, was that environmental problems, the phenomenon of waste and excessive consumption are noticeable by the respondents in today's world, and they try not to exacerbate these problems with their consumption activities. Respondents proved to be mindful of pro-ecological aspects in their buying activities, which is very satisfying.
- 4) It is satisfying that respondents commonly perceive many ecological aspects of online commerce in their shopping experience. This means that sellers include ecological products in their offers, provide ecological delivery, and that there are a lot of ecological solutions in the area of parcel packaging. Electronic sales documents and after-sales service forms have become much more widespread and customers can see increasingly better product descriptions and visuals on sellers' websites.
- 5) The survey revealed areas for improvement on the part of e-sellers, as these solutions are not yet common. Sellers could more widely implement solutions such as reserving in-store products for fitting, collecting used products in exchange for discounts, offering a reduced price for non-returnable purchases or bicycle couriers. Respondents, however, are not interested in introducing fees for ecological packaging.

The conclusions drawn from the collected results of the survey, authorize the adoption of the hypotheses assumed in the paper. The consumers are not extremely ecological and sellers also still have a lot of space for further greening in e-commerce.

The presented studies do not fully confirm the results of studies, e.g. *Green Generation Report* (2020) or WCO (2022), indicating great hopes for the greening of trade by young people. The studied population turned out to live in moderate agreement with the idea of ecological life.

The results of the studies (like Slozko, Pelo, 2014; Wu et al., 2023; Bhavsar, Samanta, 2022) proving that buyers choose payment methods considered ecological (mainly cashless and electronic). However, card payments did not dominate as in the results of Liu et al. (2008). Young consumers see the role of pro-ecological activities in e-commerce, which is confirmed by research by e.g. Łysoń (2023), and more and more of them are being noticed - partly contrary to the results of the *Together for the Earth Report* (2020). The results of e.g. Jagoda et al. (2023) regarding the choice of mainly ecological forms of delivery were also confirmed. But young consumers do not necessarily want to pay extra for ecological packaging - as in research by e.g. Villa et al. (2022).

Conclusions from the statistical analysis - although the sample was non-random - do not rule out generalizations to the youth population. Due to the lack of a sampling frame for the population of the analyzed age, the sample could be representative despite the method of selection. An interesting finding is that young consumers do not act stereotypically based on their gender and appear to become pro-environmental, increasingly mature consumers with age.

The empirical study results indicate that young consumers declare moderately pro-environmental attitudes and relatively often undertake selected actions consistent with the idea of reducing consumption and waste. At the same time, the data do not allow for the unequivocal conclusion that environmental aspects are currently the dominant factor in online purchasing decisions, meaning that the further "greening" of e-commerce remains a development direction and expectation rather than an empirically confirmed market standard. Distinguishing between observed behaviors and the postulated development of green e-commerce is crucial for the proper interpretation of the results and for designing future research, for example, to verify whether consumers' declarations of their actual contribution to the greening of e-commerce translate into actual behavior. To this end, behavioral studies based on actual transaction data should be conducted. The gap between pro-environmental attitudes and actual online purchasing decisions could also be measured". It would also be interesting to examine the impact of various factors, such as time pressure, promotion, and personalization, on the "erosion" of pro-environmental behavior.

Then again, the supply side arouses curiosity - how sellers approach the greening of e-commerce. The supply-side perspective (vendors and platforms) is also interesting – what are the actual costs of implementing environmentally friendly practices, what are the organizational and technological barriers, and what is the scale of the discrepancy between company declarations and operational practice.

The topic is therefore still a lively and open field for further research. Nevertheless it is apparent that the process of greening in e-commerce is ongoing, which gives cause for optimism in view of the confirmation of the fact that there is a move towards sustainable development in this area as well.

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THE PERCEPTION OF ARTIFICIAL INTELLIGENCE AND THE METAVERSE BY HOTEL MANAGEMENT IN MARKETING AND DATA MANAGEMENT: A CASE STUDY FROM POLAND

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Purpose: This paper aims to assess the potential application of AI and the metaverse in marketing and data management in hotels, as well as to identify areas where these technologies can support managerial activities.

Design/methodology/approach: Based on a literature review and quantitative research, the key aspects of using these tools are presented, considering both the challenges and the perspectives on their implementation in the hospitality sector. The following research questions were formulated: How does hotel management perceive the application of AI and the metaverse in marketing and data management? What challenges and perspective do hotel managers identify in the implementation of these technologies? The study was conducted using a diagnostic survey method via online platforms in 2024. It involved individuals in managerial positions, including directors and department heads in selected hotels in Poland.

Findings: The statistic analysis of the results shows that AI and the metaverse play a significant role in the hospitality industry. Managers appreciate the benefits of these technologies while also noting the potential difficulties related to their implementation.

Research limitations/implications: The study points to possible directions for future research that could contribute to a better understanding of the processes of building managerial trust in AI applications, both in the hospitality industry and other sectors. The main limitations include the relatively small and non-representative sample, limited to hotel managers in Poland, and the predominance of quantitative data, which may not fully capture the complexity of attitudes toward AI. Future studies should incorporate larger, more diverse samples and qualitative methods to provide deeper insights.

Practical implications: The study highlights the need for targeted education and training in digital competencies among hospitality managers to overcome barriers to AI adoption and improve implementation strategies.

Social implications: The findings may support a more socially responsible digital transformation by emphasizing the importance of building trust in AI technologies and considering cultural and demographic factors in the adoption process.

Originality/value: The study provides new, practical insights into specific areas of AI application and resistance within the hospitality sector, offering a basis for cross-sector comparisons and further research on AI use in service industries.

Keywords: artificial intelligence (AI); metaverse; marketing; data management; hospitality industry; management staff.

Category of the paper: Research paper.

1. Introduction

The hospitality industry faces challenges arising from dynamic market changes, increasing competition, and evolving customer expectations. It is also undergoing a significant transformation with the implementation of artificial intelligence (AI) technologies and the concept of the metaverse (Jabeen, Al Zaidi, Al Dhaheri, 2022). The global travel technology market, including AI, is growing rapidly, with intelligent hotel systems increasingly influencing service quality and customer satisfaction (Wang, 2022). The global travel technology market, including AI, is projected to grow by over 9% from 2010 to 2023 (Samala, 2022).

The ongoing digital transformation in hospitality has created new opportunities for automation, data analysis, and personalized services (Mariani, Borghi, 2023). AI-based chatbots and recommendation systems play a key role in personalizing service and enhancing service value (Casaló et al., 2025). Meanwhile, the metaverse represents a potential tool for conducting immersive marketing activities and creating virtual experiences for guests. These technologies not only improve hotel operations but also enhance customer satisfaction, which is crucial for maintaining competitiveness (Hapek, 2020). AI and the metaverse can significantly support hotel management, particularly in marketing and data management. However, their implementation poses technical, organizational, and legal challenges, requiring careful planning and adaptation strategies. Therefore, their practical applications in hospitality still require in-depth research (Dwivedi et al., 2024).

Research on AI applications in hotels is essential for understanding their impact on hotel operations and the benefits for both managers and guests (Kong et al., 2023; Pizam et al., 2022). Artificial intelligence has become a crucial tool in data analysis, process automation, and the personalization of hotel services (Mariani, Borghi, 2023). AI-driven generative chatbots and recommendation systems increasingly play a significant role in enhancing the value of hotel services (Casaló et al., 2025). Additionally, the concept of the metaverse opens new opportunities for immersive customer experiences and marketing campaigns, although its application in hospitality still requires further exploration (Dwivedi et al., 2024).

Understanding how hotel managers perceive and implement AI and metaverse technologies is vital for developing effective digital strategies. Misconceptions or lack of awareness about these tools may impede their adoption, limiting potential competitive advantages in an increasingly technology-driven market (De Cremer, Bianzino, Falk, 2023).

This study examines how hotel managers perceive the application of AI and the metaverse in marketing and data management, with a focus on identifying the challenges and opportunities associated with their implementation. It also seeks to address key research questions regarding how these technologies are viewed by hotel managers and the potential obstacles they foresee in integrating them into the hospitality industry. The following research questions were formulated:

- RQ1: How do hotel managers perceive the use of AI and the metaverse in marketing and data management?
- RQ2: What challenges and opportunities do hotel managers see in implementing AI and the metaverse in the hospitality industry?

This article addresses the issue of the use and trust in AI and metaverse tools among hotel management. Both in Poland and globally, there is a lack of research analyzing hotel managers' perceptions of artificial intelligence and the metaverse in the context of marketing and data management. Most available studies focus on technological aspects or on the perspective of customers and staff, while managers often lack sufficient knowledge about the opportunities and challenges related to the implementation of these technologies.

The goal of this study is to explore the role of AI and the metaverse in hotel marketing and data management, as well as to assess their perceived impact, potential benefits, and key challenges from the perspective of hotel management (Limna, 2022). The article aims to fill this gap by providing practical guidance and supporting informed strategic decision-making in the hospitality sector.

2. Foundations and Applications of AI and Metaverse in Hospitality

2.1. Concepts and Evolution of AI and Metaverse Technologies

Recent crises, such as the COVID-19 pandemic, have forced hotel companies and their guests to adopt advanced technologies that allow them to avoid direct physical interactions (Zaman et al., 2024; Bagozzi et al., 2022; Foroudi et al., 2023). Advances in fast communication and digital technologies have significantly influenced the development of interactions between humans and machines (Kamble et al., 2018). These interactions take place in virtual spaces and involve various entities, both human and digital. With the advent of Web 3.0, technologies such as Artificial Intelligence (AI), Virtual Reality (VR), and Augmented Reality (AR) have become ubiquitous and are applied in nearly every industry (Chen, 2023; Cicek et al., 2024; Filep et al., 2024; Gursay et al., 2022). Generative Artificial Intelligence (GenAI) represents a modern form of artificial intelligence (AI), capable of autonomously generating digital content based on prompts provided by the user (De Cremer et al., 2023; Dwivedi et al., 2024). These advanced

technologies offer hotel guests engaging and dynamic experiences that can potentially increase interest and contribute to sales growth (Huang et al., 2019; Hoyer et al., 2022; Kong et al., 2024; Liu et al., 2024; Qiu et al., 2024).

Over the last few decades, many definitions of this phenomenon have emerged. AI is considered a field of science that seeks to explain and replicate intelligent behavior using computational methods (Schalkoff, 1990). It is also described as a "multidisciplinary engineering field" encompassing many other subdisciplines (Przegalińska, Oksanowicz, 2020). However, the most universal definition was provided in the studies of Urwin (2024), who defined AI as a tool created to assist or replace human thinking. It is assumed that key components of human intelligence include the ability to remember, perception of the surrounding world, reasoning (Sternberg, 2023), learning skills, problem-solving, and achieving goals in a changing and uncertain environment (Manning, 2020). In the context of computer science, AI is defined as the ability of machines to communicate with humans without revealing their non-human nature (Jiang et al., 2022). According to B. Marr (2016), AI can be divided into three main paradigms: Symbolic AI (GOFAI – Good Old-Fashioned AI; based on rules, logic, and symbols), Statistical AI (based on the analysis of large data sets, Machine Learning, ML), and Subsymbolic AI (Deep Learning, DL, or Reinforcement Learning, RL). Additionally, hybrid AI, connectionism, evolutionary AI, agent-based systems, and AI inspired by cognitive science are also mentioned (Dellermann et al., 2019; Kaufman, Gorman, 2023; Pileggi, 2023; Tomczyk, Brüggemann, Doligalski, 2024).

The international organization OECD (2019a) defines an AI system as a machine-based system that, for specific objectives, can make predictions, recommendations, or decisions, influencing real or virtual environments. AI has seven different use cases that can coexist within the same system: hyper-personalization, conversation and human interaction, applications using pattern and anomaly detection, recognition, goal-driven systems, predictive analytics and decision support, and autonomous systems.

According to the definition by the Council of the European Union (2022), the term "metaverse" comes from the words "meta" (meaning "beyond") and "universe". It is a real-time online network built on the integration of various technologies, such as blockchain, AI, and interactive sensing technologies (KPMG China, 2022). The metaverse is a "post-reality universe," a persistent, multi-user environment that merges physical reality with digital virtuality. It relies on the convergence of technologies that enable multisensory interactions, including VR and AR, creating immersive, socially connected environments (Mystakidis, 2022). The metaverse is a three-dimensional Internet (3D) experience that combines and blurs the boundaries between reality and virtuality (Hui, 2022), where users interact through avatars, make purchases using cryptocurrencies, and work remotely.

The AI market is expected to experience significant growth over the next decade. In 2024, total global corporate investment in AI reached nearly 184 billion U.S. dollars, marking an increase of almost 50 billion compared to 2023. This impressive trend is expected to

continue, with the market surpassing 826 billion U.S. dollars by 2030 (Statista, 2025a). Also, the global metaverse market size was estimated at USD 105.6 billion in 2025 and is projected to grow at a CAGR of 37.43% from 2025 to 2030. By 2030, it is projected that the metaverse market will have 2.6 billion users, and is expected to increase to 39.7%. The metaverse market is experiencing rapid growth globally, with nations such as the United States, China, and Japan at the forefront of technological innovations and user engagement (Statista, 2025b).

2.2. The potential of AI and Metaverse in the Hospitality Industry

An important element in the context of AI in hospitality is the significant potential of using digital technologies (Kopera, 2021). Over the past few years, artificial intelligence has become an extremely important tool used in hotel management (Mnyakin, 2023). It finds wide applications, improving both operational efficiency and guest experiences. Table 1 outlines the key areas of AI usage in hotels.

The development of AI is closely linked to rapid access to large volumes of diverse data, enabled by cloud computing and big data technologies. These tools allow AI to learn and effectively use acquired information (Łapczyński, 2020; Mnyakin, 2023). Digital data has become a new production factor influencing the development and competitiveness of companies, sectors, and nations (OECD, 2019b).

In hotels, AI is mainly used to analyze guest behavior and preferences, allowing for more effective, targeted marketing campaigns (Markowitz et al., 2023). Commonly used technologies include data analysis and business intelligence systems, customer review monitoring, payment automation, and PMS for managing reservations and inventory. Other tools include chatbots, virtual assistants (such as ChatGPT), humanoid and kitchen robots, AV and conference technologies, the Internet of Things (IoT), the metaverse (VR/AR), and autonomous or electric vehicles (Kong et al., 2023).

Hotel operators place the most trust in technologies that directly support hotel operations, such as reservation and online payment systems. In contrast, more advanced solutions like kitchen robots or VR/AR are met with greater skepticism, likely due to their lower familiarity and adoption in the industry (Yin et al., 2024).

The implementation of AI in the hospitality industry offers many opportunities and benefits for businesses, but also presents numerous challenges and concerns that managers must face. As AI continues to develop, its impact on the industry will grow, transforming traditional management methods into more modern and efficient ones (Limna, 2023; Marković, Janković, Zubović, 2020; Davenport et al., 2020). Although AI will not fully replace managerial positions, it can contribute to improving the quality of their work (Mnyakin, 2023).

Table 1.*Key areas of AI technology utilization in the hospitality industry*

Areas	Description
Data Management	AI supports the analysis of interrelationships between data and other competencies, such as management skills or design.
Personalization of Guest Experience Services	AI analyzes data regarding customer needs, preferences, behaviors, and history in real-time. It provides personalized recommendations or loyalty programs, e.g., related to rooms, spa services, or restaurant preferences, increasing guest satisfaction. Hotels use AI to predict guest needs and preferences.
Process Automation	AI-based chatbots are conversational agents that can be integrated with a hotel's website or mobile app to handle guest queries, requests, and complaints. Chatbots and virtual assistants are used for check-ins, check-outs, meal bookings, recommendations, or ordering other services without staff interaction, reducing guest waiting times and increasing operational efficiency.
Guest Feedback Analysis	Processing guest feedback and ratings, identifying key areas for improvement, leading to service enhancement.
Revenue Management, Forecasting, Price Optimization	AI algorithms analyze internal and market data, predict demand, and optimize prices in real-time, adjusting offerings to the dynamic market and maximizing revenue. They conduct market segmentation, channel management, and competitor analysis.
Energy and Resource Management	Monitoring resource consumption, optimizing settings, reducing costs and environmental impact, reporting (e.g., ESG).
Security and Protection	Monitoring and protecting the premises, verifying suspicious activities, and identifying potential threats in real-time, e.g., video surveillance, facial recognition, access control, threat detection, and fraud detection.
Predictive Maintenance	AI is used to predict and prevent equipment failures or maintenance needs, reducing downtime, taking preventive actions, and improving operational efficiency, e.g., sensor networks, machine learning, real-time monitoring, and automatic notifications.

Source: own elaboration based on: Melnyk, Barna, 2022; Al-Hyari, Al-Smadi, Weshah, 2023, pp. 810-812; Kacar, 2023.

The rapid development of the tourism industry, along with the adoption of AI and machine learning, is reshaping the structure of the sector and hotel operations (Samala, 2022). Hotels increasingly rely on technology to improve service quality and guest satisfaction, from booking to checkout (Roy et al., 2020). AI enables service personalization, process optimization, and enhanced efficiency, playing a key role in guest satisfaction and loyalty, especially in luxury hotels (Jabeen et al., 2022; Nozawa et al., 2022). It can significantly influence and transform the guest experience (Bharwani, Mathews, 2021; Wang, 2022; Mariani, Borghi, 2023; Avula, Sithole, 2024).

AI is increasingly applied in customer service, marketing, and hotel operations (Limna, 2022). Marketing tools like recommendation systems, big data, and the metaverse support personalized offers and dynamic pricing (Al-Hyari, Al-Smadi, Weshah, 2023; Mariani, Borghi, 2023). High-quality intelligent systems also enhance operational efficiency and competitiveness (Hussein et al., 2022), highlighting AI's growing strategic role in hospitality (Al-Hyari, Al-Smadi, Weshah, 2023).

The literature also points to challenges and barriers that may affect the pace and scope of implementing these solutions, requiring careful analysis and the adaptation of implementation strategies to the specifics of the hospitality industry (Al-Hyari, Al-Smadi, Weshah, 2023; Mariani, Borghi, 2023). Concerns are raised regarding guest data privacy, security,

and integration with existing systems, which generates high costs for implementing the latest solutions (Hussein et al., 2022). Additional threats include questioning the effectiveness of AI and the credibility of generated information (hallucinations), as well as the limitations of algorithms, lack of creativity, empathy, and dexterity, and continuous learning that requires large amounts of data, including personal data (Lee, Qiufan, 2021). Currently, hotel management faces the challenge of building trust in AI both among customers and employees (Jia, Chi, Chi, 2025), as well as identifying the role of organizations and customers in shaping the ultimate effectiveness of AI in hotels (Chiang, Trimi, 2020).

3. Methods and Data Sources

The aim of this study is to analyze the perception of hotel managers, including their level of trust in artificial intelligence and metaverse technologies in the context of marketing and data management, as well as to identify the challenges associated with their implementation in the hospitality industry. The increasing role of AI in decision-making, process automation, and optimization of business strategies has prompted the authors to investigate the level of trust among hotel industry management in using this technology. There is an urgent need for research on the use and perception of AI in the daily tasks of managers, especially in the hospitality industry.

The study employs a quantitative survey method to analyze hotel managers' perceptions of AI and metaverse use in marketing and data management. It provides quantitative information about their adoption and the challenges associated with it (Woszczyna, Mania, 2023). The study was conducted using the Webankieta.pl platform. This method offers several advantages, including easy access for respondents, the ability to pose complex questions, flexibility in data collection, and respondent anonymity — all of which encourage honest answers and improve sample control, thereby enhancing the quality and reliability of the results (Jabeen et al., 2022).

The sample selection was purposive, meaning that population units were selected based on specific criteria (Miszczak, Walasek, 2013). In this context, the study adopts a quantitative approach, supported by statistical tools, which will allow for the assessment of the results and the analysis of respondents' attitudes toward preferences and trust in AI. The survey questionnaire was carefully designed to cover several areas, including variables related to the respondents' profile such as management level, education, work experience, workplace, hotel size (e.g., number of rooms), and hotel category (from 1 to 5 stars), according to the Polish classification of hotel facilities (i.e., hotels from 1-lowest star to 5-highest star). The classification of management levels was done according to Griffin's (2017), management levels model. The questionnaire also included variables specific to the study, such as the goals

of using AI tools in hotel work, trust in these technologies, and the benefits and difficulties associated with their use.

The survey included general and demographic questions, but due to space limitations, only six questions most relevant to the research topic were analyzed. Variables were measured using multi-point scales, including a 5-point Likert scale for trust and purpose of AI use, as well as 4- and 3-point scales for experience and proficiency with modern technologies.

The study was conducted in the first quarter of 2024. A total of 102 surveys were sent to hotels operating in Warsaw (capital of Poland), of which 88 were correctly completed, and only 35 managers had experience with AI solutions. Due to the lack of full representativeness of the sample, the study should be treated as exploratory. Nevertheless, it provides valuable information on the perception of AI technology among hotel managers, particularly in the context of their experiences and the level of trust in these technologies.

In the statistical analysis, distribution analysis of variables (frequencies and percentages) was performed. Opinions regarding the advantages of using AI (Q4) were used to assess the likelihood of its use. Odds ratios (OR) were developed using logistic regression models, where the dependent variable was the “frequency of AI tool use” (states: “using AI” and “not using AI” – lack of willingness, lack of knowledge, plans to use in the future). The results were presented as odds ratios (OR) and a 95% confidence interval (95% CI).

4. Research Results

4.1. The Respondent Profiles

The quantitative study involved 88 directors and department heads from selected hotels in Warsaw. Participation in the study was voluntary and anonymous. The managers represented three levels of management: Top Management ($n = 33$, 37.5%), including regional director, CEO, vice president, and hotel director; Middle Management ($n = 42$, 47.5%), including deputy director, chief accountant, department director/manager (e.g., HR, guest services, food and beverage, etc.); and Supervisory Management ($n = 13$, 15%), including executive chef and deputy, restaurant manager and deputy, shift supervisor, front desk manager, and housekeeping manager, etc.

The respondents were mainly managers with relatively short tenure, as 63.6% had 1 to 5 years of managerial experience, while fewer had over 10 years. In terms of education, 43.18% held a bachelor's degree, and 32.95% had a master's degree (Table 2).

Table 2.*Respondents profile characteristics (n = 88)*

Profile characteristics		Number of respondents	Percentage (%)
Education	Primary	3	3,41%
	Secondary	18	20,45%
	Higher (Bachelor's)	38	43,18%
	Higher (Master's)	29	32,95%
Tenure in a Managerial Position (in years)	Up to 1 year	1	1,14%
	1 to 5 years	55	62,50%
	5 to 10 years	22	25,00%
	10 to 20 years	10	11,36%
Place of work: Hotel Classification in Poland	1 star	1	1,14%
	2 stars	1	1,14%
	3 stars	27	30,68%
	4 stars	36	40,90%
	5 stars	14	15,90%
	Other, specify	9	10,23%
Place of work: Hotel Size (number of rooms)	Up to 50 rooms	2	2,27%
	Up to 100 rooms	11	12,5%
	Up to 150 rooms	19	21,59%
	Up to 200 rooms	27	30,68%
	Over 200 rooms	29	32,95%
Technological Proficiency	Low	17	19,32%
	Medium	58	65,90%
	High	13	14,77%
Experience with AI Technology	No experience	15	17,04%
	Low	18	20,45%
	Medium	47	53,41%
	High	8	9,09%

Source: own research.

Nearly one-third worked in large hotels with over 200 rooms, with others employed in hotels of smaller sizes. Most managers represented 4-star (41%) and 3-star (30.7%) hotels, with fewer from 5-star hotels and uncategorized establishments. The surveyed hotel managers demonstrated relatively low experience with AI technology and limited proficiency in using various advanced technologies (Table 2).

4.2. The Extent of AI Technology Usage by the Hotel Managers

To reach the target group, an initial diagnosis of the scale of AI technology usage among hotel management staff was conducted. In response to the first question (Q1) "Do respondents use AI technology for both personal and professional purposes?", out of 102 managers, only 35 (39.7%) used AI technology. Among the remaining 43 managers (48.8%), none had used this technology yet, and 17 respondents (19.3%) had only heard about AI. Seven respondents (7.95%) expressed a willingness to use AI solutions in the near future.

Based on the statistical analysis using logistic regression models, the respondents' opinions were examined regarding the likelihood of using these tools, based on characteristics such as "experience with AI technology" and "technological proficiency." It was found that "low" experience with AI technology resulted in a 79.2% lower chance of using AI solutions compared to high technological experience (OR: 0.208; 95% CI: 0.03-0.96). Similarly, those

who rated their technological proficiency as "low" had an 80.8% lower chance of using AI solutions than those with "high" technological proficiency (OR: 0.192; 95% CI: 0.04-0.84). On the other hand, individuals rating their technological proficiency as "average" had a 64.5% lower chance of using AI compared to those with "high" technological proficiency (OR: 0.355; 95% CI: 0.10-0.94).

In the next question (Q2), respondents were asked to indicate the purpose of using AI solutions in their work. Hotel management staff most frequently used these tools in marketing, particularly for marketing communication, with nearly 55% of respondents "strongly agreeing" with this statement (Table 3). The following areas (with the highest number of top ratings) included: service offer planning, recommendation systems, demand forecasting, service and guest experience personalization, and promotional campaign design. The lowest ratings were given by managers who used AI technology for customer service quality control and improvement, as well as for price management.

Table 3.

Goals of AI tool usage by the hotel managers (%) (n = 35)

Goals	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Marketing Communication (ads, brochures)	2,33%	2,33%	5,56%	35,17%	54,61%
Service offer planning	7,41%	7,41%	5,56%	37,04%	42,59%
Recommendation systems	7,41%	14,81%	11,11%	25,93%	40,74%
Demand forecasting	11,11%	11,11%	11,11%	29,63%	37,04%
Service offer personalization	3,71%	7,41%	11,11%	44,44%	33,33%
Guest service personalization	6,25%	6,25%	8,33%	46,25%	32,92%
Promotional campaign design	14,81%	7,41%	7,41%	44,44%	25,93%
Price management	20,84%	12,5%	12,5%	33,33%	20,83%
Customer service quality Control and Improvement	12,5%	16,67%	13,89%	27,78%	29,17%

Source: own research.

Regarding the next question (Q3) in the survey: "Do you believe that the metaverse (technology using AR/VR goggles) can help promote and sell offerings?", more than half of the respondents (almost 55% of 88 hotel managers) answered positively (yes). Only 19 respondents (21.59%) disagreed with this statement, while 21 respondents (approximately 24%) were undecided. The logistic regression analysis revealed that individuals who did not believe that the metaverse (technology using AR/VR goggles) could help promote and sell offerings had a 144.4% higher chance of using AI tools compared to those who answered 'yes' (OR: 2.444; 95% CI: 1.22-7.26).

The next stage of the analysis was the evaluation of the benefits resulting from the use of AI tools (Q4) by hotel managers. Among the highest-rated advantages of AI technology, managers identified more effective advertising campaigns (Table 4). This was the only case where the highest ratings dominated – 51.43% of respondents selected the answer "strongly agree". Also highly rated (with a significant lead in "agree" responses) were: improved personalization of the offer, easier data analysis, and targeted advertising. Similarly, demand

and trend forecasting, email marketing automation, more efficient use of the marketing budget, and monitoring competition were highly rated.

Table 4.

Benefits of AI utilization in hotel managers' assessment (%) (n = 35)

Benefits	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
More effective advertising campaigns	0%	8,57%	11,43%	28,57%	51,43%
Easier data analysis	0%	5,71%	14,29%	54,29%	25,71%
Improved personalization of offers	2,86%	5,71%	8,57%	60%	22,86%
Targeted advertising	0%	0%	31,43%	42,86%	25,71%
Demand and trend forecasting	2,86%	2,86%	14,29%	57,14%	22,86%
More efficient use of marketing budget	0%	5,71%	22,86%	51,43%	20%
Email marketing automation	2,86%	8,57%	14,29%	51,43%	22,86%
Monitoring competition	0%	2,86%	25,71%	45,71%	25,71%
Enhanced analysis of customer reviews	0%	17,14%	25,71%	31,43%	25,71%

Source: own research.

The next stage of this analysis was the assessment of the challenges and prospects related to the implementation and use of AI in hotels (Q5). The most significant barrier (with the highest number of "strongly agree" responses) was primarily the lack of qualified AI specialists, which posed a significant problem for the organization (table 5). Similarly, managers noted that the implementation of AI in the company is difficult due to the absence of a clear strategy, and managers require constant access to up-to-date knowledge about new trends and possibilities related to the use of these technologies. Adapting to the rapid pace of changes in the AI field and its applications, especially in ensuring ethical and responsible use of AI within the company, was also challenging. On the other hand, the hotel managers surveyed strongly agreed that investing in AI-driven solutions would bring long-term benefits to the hotel (80% positive acceptance) and that understanding and using AI technology is currently crucial for the future of the hospitality industry (over 77% positive acceptance). Furthermore, AI can improve customer service efficiency (over 75% positive acceptance). However, nearly half of the respondents are concerned that AI technologies may negatively affect the quality of customer service.

Table 5.

Challenges and opportunities in the implementation of AI technology in the evaluation of hotel managers (%) (n = 35)

Challenges / Opportunities	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Lack of qualified AI specialists is a problem in our organization	0%	11,43%	22,86%	20%	45,71%
Implementing AI in the company is difficult due to the lack of a clear strategy	5,71%	20%	17,14%	22,86%	34,29%
Managers need constant access to up-to-date knowledge about new trends and possibilities related to AI	2,86%	8,57%	20%	34,29%	34,29%

Cont. table 5.

Understanding and using AI is crucial for the future of the hospitality industry	2,86%	8,57%	11,43%	42,86%	34,29%
Investing in AI will bring long-term benefits to the hotel	2,86%	5,71%	11,43%	65,71%	14,29%
Implementing AI technology can increase the efficiency of customer service	2,86%	14,29%	17,41%	40%	25,71%
Automation using AI may negatively affect the quality of customer service	0%	25,71%	28,57%	37,14%	8,57%

Source: own research.

In summary, the data presented in Table 5 illustrate a clear dichotomy in the attitudes of hotel managers. While there is a strong conviction regarding the strategic necessity and long-term benefits of AI, the practical implementation is significantly hindered by human resource gaps and strategic uncertainty. These findings suggest that for AI to be successfully integrated into the Polish hotel industry, technological investment must be accompanied by specialized training and the development of robust ethical frameworks.

5. Discussions

The technological revolution that we are currently observing and co-creating is crucial in shaping the future (Atkinson et al., 2020; Woszczyna, Mania, 2023). AI technologies are becoming increasingly critical and inevitable in hotel management. They are capable of autonomously generating digital content based on data provided by the user in real-time (De Cremer et al., 2023; Dwivedi et al., 2024). Unlike traditional systems, this technology encompasses systems that have the ability to learn, integrate information, and adapt (Huang, Rust, 2021). This enables advanced personalization and evolution (Casaló et al., 2025).

The research showed that only 39.7% of hotel managers use AI technology, indicating a relatively low level of its adoption within the hotel industry. However, in Poland, there is a gradual increase in the use of advanced AI-powered information systems in businesses. According to the KPMG report (2023), 15% of Polish organizations were already using AI technology, with an additional 13% planning to implement it by the end of 2023.

According to the results of the own research, the low level of technological experience among hotel managers in the field of AI significantly reduces the chances of applying these tools compared to individuals with more experience. The analysis of technological proficiency indicates that individuals who assess their proficiency as low have fewer opportunities to utilize AI technology, highlighting the importance of technological skills in adapting to new solutions. Meanwhile, Poles perceive themselves as proficient in technology. According to the latest survey by Pracuj.pl, as many as 72% of respondents positively assess their digital competencies, i.e., the ability to effectively use technology, including devices, the Internet, and programs and

applications. Despite this overall technological proficiency, the implementation of advanced solutions, such as AI, faces barriers in certain sectors, including hospitality (Lendtech, 2024).

The above results suggest that the low level of experience and technological proficiency among hotel managers may stem from a lack of proper training, fear of new technologies, or resistance to change, which hinders the implementation of innovations in the hotel industry. Additionally, many technology leaders struggle to keep up with the rapid pace of technological changes. This sense of lagging may lead to hasty investment decisions, carrying the risk of high costs and exacerbating technological backlogs (KPMG, 2024). On the other hand, a higher level of technological proficiency and experience promotes greater openness to utilizing AI tools. This may result from a greater comfort in handling technology and a better understanding of its potential benefits for improving operational efficiency. Managers with higher technological competencies are more likely to implement AI solutions, which may be due to their greater inclination towards innovation and awareness of the benefits derived from their use (e-hotelarz.pl, 2023; KPMG, 2023).

The managerial staff in the hotels studied most frequently used AI tools primarily for marketing communication, service offering planning, recommendation systems, demand forecasting, guest service personalization, and promotional campaign design. The lowest ratings were given by managers who used AI technologies for customer service quality control and improvement, as well as for price management. Similarly, the research by Haleem et al. (2022) shows that the management team primarily uses AI technologies in marketing to better understand guest preferences, personalize offers, optimize advertising campaigns, and improve communication with customers. Effective use of customer knowledge allows for better offer customization and the building of strong relationships, leading to greater guest satisfaction, loyalty, and higher booking rates.

Among the benefits of using AI solutions, hotel managers identified: more effective advertising campaigns, easier data analysis, improved personalization of the offer, and targeted advertising. Similarly, demand and trend forecasting, email marketing automation, more efficient use of the marketing budget, and monitoring competition were highly rated. The benefits of using this technology enable improvements in guest satisfaction and loyalty, especially in the luxury hotel segment (Jabeen et al., 2022; Nozawa et al., 2022), which means that AI applications in the hospitality industry can enhance or transform guest experiences (Prentice et al., 2020; Bharwani, Mathews, 2021; Wang, 2022; Mariani, Borghi, 2023; Avula, Sithole, 2024). As a result, AI technology has become a key element in improving operational efficiency, service quality, and increasing hotel revenues (Jabeen et al., 2022; Limna, 2022; Pizam et al., 2022; Singh et al., 2022; Mariani, Borghi, 2023). Among other things, solutions that streamline data and operations management, including machine learning, chatbots, virtual assistants, smart mobile apps (MobApps), the Internet of Things (IoT), robots, and building management systems, contribute to service automation, improved energy efficiency, and the optimization of hotel processes (Pizam et al., 2022; Casalo et al., 2025).

Consumers, when making travel decisions, choose from hotels with different features. Innovations in automation technology change these options and consumer experiences. Knowledge of the acceptance of these technologies is key for marketers, travel agencies, and hotels as it affects their adoption and usage (Ukpabi, Karjaluoto, 2017). Furthermore, AI-based evaluation systems provide more accurate and objective results than traditional methods (Wang, 2022). They also allow for price strategy optimization, offer personalization, and increase customer engagement (Al-Hyari, Al-Smadi, Weshah, 2023; Mariani, Borghi, 2023). Increasing attention is being paid to marketing-supporting technologies, such as VR/AR or the metaverse, which offer engaging and dynamic experiences to hotel guests and can contribute to increased interest and sales (Hoyer et al., 2022; Huang et al., 2019; Kong et al., 2024; Liu et al., 2024; Qiu et al., 2024). The importance of integrating technology with traditional hospitality practices is emphasized to provide guests with a personalized and unforgettable experience (Bharwani, Mathews, 2021).

In the context of data analysis, BI, and Metaverse (VR/AR) technologies, the survey results were not spectacular, with only about 40% positive responses. However, more than half of hotel managers believed that the metaverse could support the promotion and sales of offerings. Logistic regression analysis showed that those who did not believe that the metaverse and AR/VR technologies could help with promotion and sales had a higher chance of using other AI tools compared to those who answered "yes". This suggests that individuals skeptical about the metaverse's potential in promotion and sales may be more open to alternative technologies, like AI, and more likely to implement them in their marketing or operational activities. Metaverse technology is often associated with games, as it initially developed mainly within the context of virtual worlds and online games (e.g., Second Life, Minecraft). Over time, the metaverse has come to be seen as a space with wide applications, including marketing, trade, education, and tourism. In marketing, it has become a platform attracting companies that want to reach younger generations and engage consumers interactively. Examples such as virtual stores, events, and in-game ads show the growing potential of the metaverse, especially in the context of AR/VR technology (McKinsey.com, 2022; e-hotelarz.pl, 2023; Akim, 2024). Through the metaverse, people can experience cooking and preparing meals in restaurants, virtual flights, hotel suites, tours, business meetings, and conferences (Tul-Krzyszczuk, 2022). According to the McKinsey report (2022), the importance of these technologies in marketing is growing. The metaverse provides a new space for brands, allowing them to engage consumers in an innovative way and develop internal capabilities and brand innovations in new directions. Additionally, the metaverse has the potential to become a new primary marketing channel, transforming the way brands connect with audiences in the digital world (Akim, 2024). In Poland, there are also noticeable investments in the metaverse, mainly in the services, banking, and retail sectors. According to estimates from Meta, the Polish metaverse market could reach a value of between 5 and 10 billion euros by 2035 (bankier.pl, 2024). Virtual experiences will not completely replace real customer experiences in hospitality.

According to the research by Gursoy, Malodia, and Dhir (2022), while visual and auditory stimuli are relatively easy to replicate, recreating taste and smell stimuli in the metaverse is still not possible.

The analysis of the challenges and prospects related to AI implementation in hotels revealed several key difficulties. The biggest barrier was the lack of qualified AI specialists and the absence of a clear strategy for implementing these technologies. Managers also emphasized the need for continuous access to up-to-date knowledge about AI trends and its ethical use. Therefore, to minimize risks, it is essential to ensure proper data security against attacks, provide employee training, and offer post-implementation support (Wang, 2022). While the surveyed managers recognize the long-term benefits of investing in AI, especially in improving customer service efficiency, some expressed concerns that the use of AI technologies could negatively impact the quality of customer relationships in certain cases. On one hand, AI can increase guest satisfaction through personalized expectations and faster service, thereby improving operational efficiency and gaining a competitive edge in the market. On the other hand, high-quality service, including interpersonal relationships, is crucial for guest loyalty, which presents a challenge for hoteliers in implementing new technologies. Therefore, it is essential that employees are well-prepared to effectively use AI technologies, which will help improve the quality of guest service. To overcome the challenges of AI implementation, a gradual introduction of this technology will be necessary, based on education, transparency, and ensuring user comfort and security (Prentice et al., 2020; Nam et al., 2021).

6. Conclusions and Further Research

The study found that the implementation of AI technology in the hospitality industry remains at a relatively low level, despite managers recognizing its potential benefits. This points to adoption barriers such as a lack of technological competence, resistance to change, ethical concerns, and insufficient implementation strategies. In the context of global trends, where AI is becoming a key element in operational management, the hospitality industry in Poland faces the challenge of adapting these solutions more quickly.

From a practical perspective, the study emphasizes the importance of education and training for management in new technologies. A high level of digital competence leads to greater openness to innovation and a better understanding of its potential benefits. The results also suggest the need for more comprehensive AI implementation strategies that address both technological and organizational aspects, minimizing resistance to change.

The analysis showed that managers most frequently use AI in marketing, service personalization, and demand forecasting, but less so in service quality management or pricing policy. They also appreciate AI's support in data management. This points to the need for further

research on the factors influencing the level of AI use in different aspects of hotel operations. From a broader perspective, the study's results may have implications for other service sectors (e.g., tourism or retail), where AI technology can improve operations and increase business competitiveness. Furthermore, the findings could serve as a basis for comparative research between different service industries in terms of AI use.

In terms of future research, it is important to delve into trends in AI development and its long-term impact on operational efficiency and customer relationships. There is a need to analyze how AI affects guest loyalty and satisfaction during hotel stays. Additionally, it would be valuable to examine the impact of demographic and cultural factors on the acceptance and use of AI by hotel management. Future studies may also focus on ways to overcome implementation barriers and build trust in AI technologies among managers and employees in the service sector. An interesting research direction could also be the variation in attitudes and readiness to implement AI depending on the type of hotel. Due to limitations in quantitative data, future research should consider qualitative methods, such as in-depth interviews or focus groups, to obtain more detailed information on managers' attitudes and experiences.

In conclusion, the study provides valuable insights for practitioners and decision-makers in the hospitality industry, suggesting the need for increased investment in the development of technological competencies and the creation of effective AI implementation strategies. Ongoing digitization and AI development create new opportunities for the industry, and their proper use can contribute to improving service quality, increasing competitiveness, and enhancing guest satisfaction.

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HANDLING NON-POSITIVE VARIABLES IN DATA ENVELOPMENT ANALYSIS

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Purpose: The purpose of this paper is to identify and compare the main extensions of Data Envelopment Analysis (DEA) that enable efficiency measurement in the presence of non-positive input and output data. The study aims to examine how the choice of method affects efficiency classification and ranking, addressing a gap in the literature where existing contributions are dispersed and method-specific.

Design/methodology/approach: The study follows a mixed-method research design. A systematic literature review was conducted using the Scopus database to identify DEA models capable of handling negative data. This was supplemented by semi-structured interviews with five academic experts specializing in DEA to validate the relevance and practical use of the identified approaches. A simulation experiment was then performed using a synthetic dataset of 80 decision-making units representing banks, containing both positive and negative variables. Four widely applied models were compared: the Range Directional Model, the Modified Slacks-Based Measure, the Semi-Oriented Radial Measure, and a Two-Stage DEA model.

Findings: The results indicate that efficiency classification is strongly dependent on the selected DEA model. The number of units identified as efficient differs substantially across methods, with the Two-Stage DEA producing the strictest efficiency frontier and the Range Directional Model the broadest. At the same time, rank-order correlations across models remain consistently high, suggesting that relative performance rankings are largely preserved despite differences in frontier definition.

Research limitations/implications: The study is limited by the use of a synthetic dataset and a small number of expert interviews, which may constrain external validity. Future research should apply the compared models to empirical datasets from different sectors and conduct robustness and sensitivity analyses.

Practical implications: The findings emphasize the need for explicit, purpose-driven model selection in DEA studies involving negative data, as methodological choices directly influence efficiency benchmarks and managerial conclusions.

Social implications: By increasing transparency in efficiency measurement, the study may support more informed decision-making in areas such as banking and public administration, contributing to improved resource allocation.

Originality/value: The paper offers a comprehensive synthesis and direct comparison of major DEA models designed to handle non-positive data, demonstrating that efficiency is a model-dependent construct and providing guidance for researchers and practitioners.

Keywords: Data Envelopment Analysis; negative data; efficiency measurement; benchmarking; banking sector.

Category of the paper: Research Paper.

1. Introduction

The concept of efficiency, alongside notions such as performance and effectiveness, has always stood at the core of business studies and organizational research. The etymology of the term *efficiency* traces back to the Latin word *efficio*, which conveys meanings such as to *perform*, *complete*, *execute*, or *produce* (Rybicki, 2005). Conversely, according to the ISO 9000 standard, efficiency is defined as the ratio between achieved results and utilized resources. Bielski (1992) offers a particularly noteworthy conceptualization of efficiency, distinguishing between two perspectives. The deliberate approach focuses on predefined organizational goals, emphasizing decision-making that minimizes resource utilization. Conversely, the systematic approach underscores the importance of the organizational environment and the capacity to acquire the necessary resources from it Bielski (1992). However, Drucker (1963) provided the simplest yet meaningful definition: *efficiency is concerned with doing things right*.

In recent years, there has been a growing academic interest in utilizing the Data Envelopment Analysis (DEA) method to assess the efficiency of various economic systems. Conventional Data Envelopment Analysis (DEA) models have been developed based on the assumption that all inputs and outputs are non-negative (Maryam, Rostamy-Malkhalifeh, 2015). This method's growing adoption and popularity has highlighted a critical need to address the challenge posed by negative data, a common phenomenon in practical, real-world scenarios (Maryam, Rostamy-Malkhalifeh, 2015). DEA is a non-parametric methodology that employs linear programming techniques to evaluate the efficiency of units called Decision Making Units (DMUs). This approach incorporates multiple inputs and outputs across various units to determine relative technical efficiency. Within the DEA framework, efficiency is defined as the ratio of the weighted sum of outputs to inputs. A key attribute of DEA lies in its flexible and adaptable structure, which is grounded in the data available for analysis (Xie et al., 2021). The origins of the method can be traced back to Farrell's foundational work (Farrell, 1957), initially applied within the agricultural sector. The term Data Envelopment Analysis was subsequently introduced by Charnes et al. (1978), with further developments contributed by Banker et al. (1984). Efficiency in DEA is calculated as the ratio of weighted outputs to weighted inputs, producing values that range between zero and one (Walczak, Marcinkiewicz, 2022). The efficiency ranking of units is established by computing these ratios across all units in the dataset (Andersen, Petersen, 1993). A unit is deemed efficient if its efficiency ratio reaches the efficiency frontier, represented by a value of one. Units with ratios below one are classified as inefficient (Antunes et al., 2021). In essence, DEA facilitates the distinction

between efficient and inefficient units by evaluating their input utilization relative to output production. Additionally, DEA integrates the concept of benchmarking, as highlighted by Ruiz and Sirvent (2019), who stated, *Using DEA for benchmarking ensures an evaluation in terms of targets that are both attainable and represent best practices*.

Two basic models of Data Envelopment Analysis (DEA) can be identified: the CCR model and the BCC model. The CCR model, developed by Charnes *et al.* (1978), is based on the assumption of constant returns to scale (CRS) (Gizaw, 2019). In contrast, the BCC model, introduced by Banker *et al.* (1984), serves as an extension of the CCR model. This model operates under the assumption of variable returns to scale (VRS) (Gizaw, 2019). The presence of negative data in Data Envelopment Analysis poses a fundamental methodological problem because basic DEA models are constructed on the assumption that all input and output values are nonnegative (Charnes *et al.*, 1978). When variables take on negative values, the input–output ratios that form the basis of DEA efficiency measurement become mathematically undefined, leading to infeasibility or meaningless efficiency scores (Portela *et al.*, 2004). Moreover, the core axioms of DEA, including free disposability and monotonicity, are violated when data include negative observations, since increasing a negative output or decreasing a negative input may not correspond to a genuine improvement in performance (Cooper *et al.*, 1999)

This research involves a comparative review of previous studies focusing on methodologies for managing negative data within DEA frameworks, with particular attention to their implications for efficiency measurement and practical application.

Based on the initial literature review the following research questions were posed:

Q1. What are methods used for dealing with negative data while implementing DEA method?

The literature review revealed that, although numerous Data Envelopment Analysis (DEA) models have been developed to address the problem of non-positive variables, there is still a lack of comprehensive publications that synthesize these contributions. Existing studies tend to concentrate on developing new model variations or applying them within specific sectors. This study contributes to the literature in several ways. First, it provides a structured synthesis of the main DEA extensions designed to handle non-positive data, focusing on models that are most frequently applied in practice rather than on isolated methodological proposals. Second, it offers a direct, head-to-head comparison of these models using a common dataset, which allows differences in efficiency frontiers and rankings to be attributed solely to methodological choices. Third, by combining a systematic literature review with expert interviews and a controlled simulation experiment, the study links theoretical model properties with their practical implications for efficiency assessment.

Q2. How does the implementation of particular methods of dealing with non-positive values influence the final result of Data Envelopment Analysis?

The article seeks to conduct a comparative analysis of results obtained through selected models, highlighting their relative effectiveness and practical utility. In this way, the study not only fills an important gap in the literature but also offers readers a structured overview of available approaches and practical guidance on how selecting a certain method influences on the results.

2. Literature Review

The Scopus database was selected for the research, using the following search terms: “DEA” OR “Data Envelopment Analysis” AND “negative” OR “undesired”. The search was restricted to abstracts containing the specified keywords. This initial search yielded 2055 documents. Further refinement of the selection was performed and described in Table 1.

Table 1.
Literature Review: Refinement of the selection

Criterion	No of papers fulfilling
Search terms on Scopus: “DEA” OR “Data Envelopment Analysis” AND “negative” OR “undesired”	2005
Only articles and book chapters	1987
Only final versions	1856
Only documents in English	1691
Collocation of word “negative” or “undesired” with “data”	98

These constraints resulted in a reduction of the available documents. No geographical constraints were introduced. Each article's abstract was then reviewed to assess how the terms *negative* and *undesired* were applied. It was found that the database contained articles where the term *negative* was frequently associated with words such as *influence*, *effect*, and *ratio*. However, in the context of the present study, the terms *negative* and *undesired* were specifically intended to describe *data*, *variable(s)*, *input(s)*, or *output(s)*. Notably, 98 articles employed the term *negative* about *data*. Surprisingly, no articles that used the term *undesired* in conjunction with *data* were found.

To avoid relying solely on database inclusion, an additional journal quality screening was conducted. Only journals indexed in Scopus or in the Web of Science Core Collection were retained. Journals classified in Q1–Q3 according to the Scimago Journal Rank were considered acceptable, while Q4 journals and titles without quartile assignment were excluded. To further reduce the inclusion of marginal outlets, a minimum impact threshold was applied: Journal Impact Factor (JCR) of at least 1,0 or CiteScore of at least 1,0. 54 articles published in journals not meeting these criteria were removed from the final sample.

After examining the references in the retrieved articles and reviewing the citations, it was determined that some important papers in the field were absent from the final selection. Consequently, the author decided to include an additional eight papers, following a thorough reevaluation of their quality and the reliability of the journals which they were published in. The backward snowballing method was incorporated. A subsequent review was conducted based on the 54 articles that met these criteria.

Ali and Seiford (1990) were among the first researchers to address the issue of handling non-positive data in Data Envelopment Analysis (DEA), focusing on the presence of zero values. They demonstrated that affine displacement of undesirable data does not impact the efficiency frontier; however, in the context of the BCC model, such displacement can influence the efficiency scores of inefficient units (Ali, Seiford, 1990). This work was further advanced by Pastor (1994), who proposed increasing the values of undesirable variables by adding a sufficiently large positive constant, as referenced in the work of Portela *et al.* (2004). Pastor's approach was subsequently adopted by Seiford and Zhu (2002) and Bowlin (1998). Building on this foundation, Lovell and Pastor (1995) developed a DEA variant that employs a weighted sum of slacks, where the weights correspond to the inverse of the standard deviations of each input and output associated with the slack. This methodology was later extended by Pastor (1996), and incorporated by Thrall (1996), Tone *et al.* (2020), as well as Cheng *et al.* (1999). For cases where inputs or outputs are entirely non-positive, Scheel (2001) proposed treating these variables as positive outputs or inputs. This approach was subsequently employed by other researchers, including Cheng *et al.* (2013), and Zhu (2003). Halme *et al.* (2002) noted that Zhu, in an unpublished manuscript from 1994, suggested a complex method involving data translation and the application of controlled envelopment analysis concepts. Halme *et al.* (2002) further proposed replacing interval scale variables with corresponding pairs of ratio scale variables, provided the derived variable is computed as the difference between two ratio-scale variables. This method was later adopted by Pastor and Ruiz (2007), Dehnohalaji *et al.* (2010), and Mohammadpour *et al.* (2015). Portela *et al.* (2004) introduced the Range Directional Model (*RDM*), which handles non-positive variables without requiring data transformation. It illustrates the concept of variable returns to scale, and it is not possible to integrate alternative returns to scale assumptions within this framework. This method, grounded in the directional distance function, was further developed by Pastor and Ruiz (2005) and adopted by researchers such as Asmild and Pastor (2010), Peykani *et al.* (2022), Yousefi *et al.* (2019), Tavana *et al.* (2018), as well as Banihashemi and Navidi (2017). Sharp *et al.* (2007) proposed the Modified Slack-Based Measure (*MSBM*), which accommodates both positive and negative data. This model addresses the absence of translation invariance found in the slacks-based measure model by incorporating concepts from the range directional model (*RDM*). By considering individual input and output slacks, the *MSBM* model offers a more accurate assessment of inefficient units. Consequently, it typically results in lower efficiency scores for inefficient DMUs compared to the *RDM* (Sharp *et al.* (2007). This method has been utilized by other

researchers, including Cui, et al., (2022), Wang et al. (2005), and Lee et al. (2017). Another prominent approach for handling negative data involves partitioning positive and negative variables. Emrouznejad et al. (2010) applied this concept to propose the Semi-Oriented Radial Measure (*SORM*) for efficiency evaluation, which was later refined by Kazemi et al. (2014), as well as Kaffash et al. (2018). It transforms each input-output variable fundamentally as the sum of two components: one representing its negative value and the other its positive value. This representation offers the benefit of allowing the negative aspect of a variable to be addressed in absolute terms, thereby presenting it in a positive format without the need for arbitrary adjustments to the origin that might otherwise be required to obtain positive values (Matin et al. 2014). This method has been widely adopted by researchers, including Mo et al. (2020), Emrouznejad et al. (2010), Kenjegalieva et al. (2011), Toloo et al. (2015). Kenjegalieva et al. (2011), and Kumari et al. (2024). Cheng et al. (2013) introduced a modified version of the traditional radial DEA model, replacing original input and output values with their absolute values. This method was subsequently employed by Tung et al. (2018). Izadikhah and Saen (2016) proposed a two-stage DEA model where each unit is structured as two interconnected sub-units, with the outputs of the first stage serving as inputs for the second stage. This two-stage framework operates in the context of undesirable data, where the initial stage generates the final outputs of the network, which subsequently serve as inputs for the second stage. This innovative approach has been applied by researchers such as Mukherjee et al. (2024), Hsu et al. Chiu (2023), and Singpai and Wu (2021). Finally, Lin and Chen (2017) introduced a super-efficiency model based on the directional distance function, which was later expanded upon by Lin and Liu (2019).

Based on the literature review, it can be concluded that the two-stage DEA model introduced by Izadikhah and Saen (2016), the semi-oriented radial measure (*SORM*) developed by Emrouznejad et al. (2010), the range directional model (*RDM*) proposed by Portela et al. (2004), and the Modified Slack-Based Measure (*MSBM*) introduced by Sharp et al. (2007) are among the most widely adopted methods. This selection is corroborated by other researchers, such as Kaffash et al. (2018), although they did not mention the two-stage DEA model. This omission is likely attributable to the fact that the first paper on this model was published in 2016, while their selection was made in 2018, and the two-year period may not have been sufficient for the new methodology to gain attraction among scholars. In general, methodologies developed post-2000 have been frequently utilized in a substantial number of studies.

3. Methodology

3.1. Extended models of Data Envelopment Analysis

As mentioned earlier, four models have been selected for the comparative analysis. This section provides their technical overview, after which the models will be tested on datasets containing negative values to examine their impact on efficiency results.

The Range Directional Model is grounded in the Directional Distance Function (DDF) methodology (for VRS) (Chambers et al., 1996, 1998), which measures inefficiency by expanding outputs and contracting inputs along a chosen direction:

$$\max = \beta_o \quad (1)$$

Subject to:

$$\sum_{j=1}^n \lambda_j y_{rj} \geq y_{ro} + \beta_o g_{yr}, r = 1, \dots, s, \quad (2)$$

$$\sum_{j=1}^n \lambda_j x_{ij} \leq x_{io} - \beta_o g_{xi}, i = 1, \dots, m, \quad (3)$$

$$\sum_{j=1}^n \lambda_j = 1, \lambda_j \geq 0, g_{xi} \geq 0, g_{yr} \geq 0 \quad (4)$$

The model mentioned above was further modified by Portela et al. (2004) to address cases where some values are negative, so that it always produces feasible improvement directions. They have also introduced an ideal point - defined by the maximum observed outputs and the minimum observed inputs across all units. Based on this reference, two vectors were determined (5) (6), which represent the potential range of improvement for unit o.

$$R_{ro} = \max_j \{y_{rj}\} - y_{ro}, r = 1, \dots, s \quad (5)$$

$$R_{io} = x_{io} - \min_j \{x_{ij}\}, i = 1, \dots, m \quad (6)$$

Build on the (5) and (6), the Range Directional Model was introduced.

$$\max = \beta_o \quad (7)$$

Subject to:

$$\sum_{j=1}^n \lambda_j y_{rj} \geq y_{ro} + \beta_o R_{ro}, r = 1, \dots, s, \quad (8)$$

$$\sum_{j=1}^n \lambda_j x_{ij} \leq x_{io} - \beta_o R_{io}, i = 1, \dots, m, \quad (9)$$

$$\sum_{j=1}^n \lambda_j = 1, \lambda_j \geq 0, \quad (10)$$

The Range Directional Model was originally formulated as a single-stage approach, where a decision-making unit is treated as a “black box” that transforms inputs into outputs. Building upon this concept, Tavana et al. (2018) incorporated the model into a two-stage DEA, in which the internal processes of each DMU are explicitly considered.

In the two-stage DEA framework, each DMU is decomposed into two sub-processes:

- Stage 1 (S1): transforms initial inputs x_{ij} into intermediate products z_{dj} .
- Stage 2 (S2): consumes the intermediate products z_{dj} to generate the final outputs y_{rj} .

Accordingly, the overall efficiency of a DMU is determined as a composition of the efficiencies of the S1 and S2.

The two-stage DEA is constructed by introducing two ideal points, separately for S1 and S2:

$$I' = \left(\max_j z_{dj}, \min_j x_{ij} \right), I'' = \left(\max_j y_{rj}, \min_j z_{dj} \right) \quad (11)$$

Based on these reference points, two improvement direction vectors (11) are defined, representing the ranges of possible improvement for each stage.

The objective function of the two-stage RDM is specified as:

$$\max w_1 \theta_1 + w_2 \theta_2 \quad (12)$$

where θ_1 and θ_2 represent the improvement parameters for S1 and S2, respectively, while w_1 and w_2 are the importance weights assigned to each stage ($w_1 + w_2 = 1$). In this analysis $w_1 = w_2 = 0.5$.

The above is subject to:

At the S1:

$$\sum_{j=1}^n \lambda_j x_{ij} \leq x_{ip} - \theta_1 R_{x_i}^1, i = 1, \dots, m, \quad (13)$$

$$\sum_{j=1}^n \lambda_j z_{dj} \geq z_{dp} - \theta_2 R_{z_d}^1, d = 1, \dots, D, \quad (14)$$

At the S2:

$$\sum_{j=1}^n \mu_j z_{dj} \leq z_{dp} - \theta_2 R_{z_d}^2, d = 1, \dots, D, \quad (15)$$

$$\sum_{j=1}^n \mu_j y_{rj} \geq y_{rp} - \theta_2 R_{y_r}^2, r = 1, \dots, s, \quad (16)$$

Additional convexity conditions apply:

$$\sum_{j=1}^n \lambda_j = 1, \sum_{j=1}^n \mu_j = 1, \lambda_j, \mu_j \geq 0 \quad (17)$$

Linkage constraint:

$$\sum_{j=1}^n \lambda_j z_{dj} = \sum_{j=1}^n \mu_j z_{dj}, d = 1, \dots, D, \quad (18)$$

Efficiency scores are thus expressed as (ρ_1 at the stage 1, ρ_2 at the stage 2, ρ as overall efficiency)

$$\rho_1 = \theta_1^*, \rho_2 = \theta_2^*, \rho = w_1 \rho_1 + w_2 \rho_2 = 1 - (w_1 \theta_1^* + w_2 \theta_2^*) \quad (19)$$

Building on the vectors R_{ro} , and R_{io} , suggest by Portela *et al.* (2004) Sharp *et al.* (2005) introduced the Modified Slacks-Based Measure (MSBM), which extends classic Tone's (2001) SBM model. By incorporating the SP Range into the normalization of slacks, the MSBM ensures both unit-invariance and translation-invariance. The model is formulated as:

$$\rho = \min \frac{1 - \frac{1}{m} \sum_{i=1}^m \frac{s_i^-}{\bar{p}_i}}{1 + \frac{1}{s} \sum_{r=1}^s \frac{s_r^+}{\bar{p}_r^+}} \quad (20)$$

subject to standard DEA feasibility constraints, where s_i^- and s_i^+ denote input and output slacks, respectively. The efficiency score ρ lies in the range $[0,1]$, and equals 1 only if all slacks are zero.

Last, but not least Semi-Oriented Radial Measure (SORM) suggested by Emrouznejad et al. (2010). Since the negative values in the data may occur two index sets are defined:

$$I = \{i : x_{ij} \geq 0 \forall j\}, L = \{l : \exists j, x_{lj} < 0\} \quad (21)$$

$$R = \{r : y_{rj} \geq 0 \forall j\}, K = \{k : \exists j, y_{kj} < 0\} \quad (22)$$

Later, the negative data is decomposed into non-negative parts.

$$x_{lj} = x_{lj}^1 - x_{lj}^2, x_{lj}^1 = \max(x_{lj}, 0), x_{lj}^2 = \max(-x_{lj}, 0) \quad (23)$$

$$y_{kj} = y_{kj}^1 - y_{kj}^2, y_{kj}^1 = \max(y_{kj}, 0), y_{kj}^2 = \max(-y_{kj}, 0) \quad (24)$$

While the two stage DEA, SORM, and RDM are directionals models, which means there is not clear input or output orientation, the MSBM explicitly evaluates inefficiency through input and output slacks, thus allowing for a more direct interpretation in terms of input reduction and/or output expansion.

For the evaluation of a DMU j_0 the input-oriented model is formulated as:

$$\min h \quad (25)$$

Subject to:

$$\sum_{j=1}^n x_{ij} \lambda_j - h x_{ij_0} \leq 0 \quad \forall i \in I, \quad (26)$$

$$\sum_{j=1}^n x_{lj}^1 \lambda_j - h x_{lj_0}^1 \leq 0, \sum_{j=1}^n x_{lj}^2 \lambda_j - h x_{lj_0}^2 \geq 0 \quad \forall l \in L, \quad (27)$$

$$\sum_{j=1}^n y_{rj} \lambda_j \geq y_{rj_0} \quad \forall r \in R, \quad (28)$$

$$\sum_{j=1}^n y_{kj}^1 \lambda_j \geq y_{kj_0}^1, \sum_{j=1}^n y_{kj}^2 \lambda_j \leq y_{kj_0}^2 \quad \forall k \in K, \quad (29)$$

$$\sum_{j=1}^n \lambda_j = 1, \lambda_j \geq 0 \quad (30)$$

Analogously, the output-oriented version is expressed as:

$$\min \varphi \quad (31)$$

$$\sum_{j=1}^n x_{ij} \lambda_j \leq x_{ij_0} \quad \forall i \in I, \quad (32)$$

$$\sum_{j=1}^n x_{lj}^1 \lambda_j \leq x_{lj_0}^1, \sum_{j=1}^n x_{lj}^2 \lambda_j \geq h x_{lj_0}^2 \quad \forall l \in L, \quad (33)$$

$$\sum_{j=1}^n y_{rj} \lambda_j - \varphi y_{rj_0} \geq 0 \quad \forall r \in R, \quad (34)$$

$$\sum_{j=1}^n y_{kj}^1 \lambda_j - \varphi y_{kj_0}^1 \geq 0, \sum_{j=1}^n y_{kj}^2 \lambda_j - \varphi y_{kj_0}^2 \leq 0, \quad \forall k \in K, \quad (35)$$

$$\sum_{j=1}^n \lambda_j = 1, \lambda_j \geq 0 \quad (36)$$

For practical applications, it is necessary to ensure the models are bounded. The following conditions hold:

- The input-oriented model is bounded if and only if:

$$d_{j_0} = \max \left\{ \max_{i \in I} x_{ij_0}, \max_{l \in L} x_{lj_0}^1 \right\} > 0 \quad (37)$$

- The output-oriented model is bounded if and only if:

$$b_{j_0} = \max \left\{ \max_{r \in R} y_{rj_0}, \max_{k \in K} y_{kj_0}^1 \right\} > 0 \quad (38)$$

- The output-oriented model is bounded if and only if:

$$a_{j_0} = \min(d_{j_0}, b_{j_0}) > 0 \quad (39)$$

3.2. Supplementary findings test

To validate the findings of the literature review, a qualitative research, based on semi-structured interviews with five academic experts specializing in Data Envelopment Analysis (DEA) was deployed. The interview guide was designed following a systematic framework. Kallio et al. (2016) proposed a five-step process for developing semi-structured interviews, which includes defining the aim, reviewing the literature, drafting questions, piloting, and refining. This study followed that model to ensure validity and reliability. The final guide covered five thematic blocks (Castillo-Montoya, 2016): (1) general background and DEA experience, (2) challenges with negative variables, (3) methodological preferences, (4) practical applications, and (5) final remarks. The interviews were conducted via online conferencing platforms, each lasting approximately 45 minutes. Sessions were not recorded, yet instant transcription was turned on. While the participants' backgrounds ranged from finance and public administration to logistics or banking, there was strong convergence in their responses: negative data is both a recurrent phenomenon and a methodological challenge in DEA, and its treatment directly influences efficiency scores, rankings, and benchmarks. Most of the experts (experts A, C, E) emphasized the Range Directional Model. They described it as particularly effective in complex network settings, because directional goals can be aligned with policy or managerial priorities. MSBM was widely highlighted (experts A, C, D) as a method that provides conservative efficiency estimates by penalizing unaddressed slacks. Experts explained that MSBM avoids the inflation of efficiency scores that may occur in radial models when negative values are present. This method was consistently valued as a diagnostic tool that goes beyond ranking to show where inefficiencies reside, making it attractive for regulators and managers seeking actionable improvements. Two experts (Expert B and D) reported favorably on SORM, while three experts (Expert B, C, and E) highlighted the advantages of two-stage DEA formulations. The consensus was that multi-stage models not only allow the inclusion of negative values but also provide more detailed guidance for targeted improvements.

Participants' answers undergo thematic and qualitative analysis, which resulted in following statements:

1. Issue with applicability of non-positive data in Data Envelopment Analysis is common, classic models are unable to deal with such variables, yet while analysis real world problems such figures cannot be omitted, which in turn lead to the need of variable or DMU exclusion.
2. List of extended/modified Data Envelopment Analysis methods yielded based on both, the literature review and semi-structured interviews is identical.

The author considered limitations to ensure that all necessary measures were taken to mitigate the negative influences caused by potential limitations. For studies with multiple participants, the workload can delay reporting and reduce efficiency. Thus, a group of 5 experts was selected. The author, based on the initial review, chose only these researchers whose

portfolios are characterized by a high volume of papers involving Data Envelopment Analysis. Taking into consideration that popularity of Data Envelopment Analysis may differ across different countries, experts from 3 countries (4 universities) were included in analysis. Although some of the limitations were possible to be mitigate, others should be taken into consideration while interpreting the article's findings.

3.3. Simulation experiment design

To evaluate and compare the performance of different DEA extensions designed to handle negative data, a synthetic dataset was constructed. The dataset comprises 80 decision-making units (DMUs), each representing a hypothetical banking institution. For each DMU, seven inputs and three outputs were generated, reflecting variables that are commonly used in efficiency studies of the banking sector. Examples of the input variables include staff (measured as full-time equivalents), the number of branches and ATMs, operating expense changes, cost of funds, risk-weighted assets, and changes in the ratio of non-performing loans. The outputs reflect financial and business performance: net interest income, non-interest income, and loan growth rates.

Because the aim of this study is methodological rather than empirical, the dataset was not drawn from banking records but generated artificially. To ensure that the data resemble realistic banking sector values, while still allowing for the presence of both positive and negative figures, the GPT-5 large language model was employed (developed by OpenAI) to design and generate the data. The model was instructed to create variable distributions reflecting the economic and financial logic of the sector. Randomness was introduced via normally distributed draws, clipped to maintain plausible ranges (operating expense changes between -30% and $+40\%$, loan growth between -40% and $+60\%$, cost of funds between -200 and 600 basis points).

The bounds for operating expense changes were based on empirical evidence from the banking and merger literature. Reported post-merger cost savings in noninterest or operating expenses typically range between 15% and 40% , with documented declines of around 30% within the first year (DeYoung, 1993; Board of Governors of the Federal Reserve System, 1998). These findings support the use of -30% as a conservative lower bound. At the same time, institutional evidence shows that operating expenses may temporarily increase due to restructuring and integration costs, with year-on-year increases of up to 40% reported in practice (Central Bank of the Republic of Turkey, 2020). Together, these studies justify the -30% to $+40\%$ interval as a plausible range for operating expense changes. While Dang (2019) observed the yearly growth of banks ranges from over 90% to -45% , Godlewski and Weill (2018) based on the data from banks belonging to the Bank Polskiej Spółdzielczości indicates that in such specific case the growth is lower from around 50% to -15% . These discrepancies highlight cross-country and sample-specific heterogeneity, which motivated the use of intermediate values as conservative bounds for the upper and lower limits in the simulation. Regarding bank saving costs, the empirical evidence shows that they may temporarily decline

by more than 150 basis points relative to pre-crisis benchmarks (Reserve Bank of New Zealand, 2024), justifying a -200 bps lower bound. Conversely, periods of monetary tightening and financial stress have been associated with increases in funding costs of several hundred basis points, with documented cases reaching approximately 600 basis points (European Central Bank, 2024; Powell, 2002).

The resulting dataset was exported into Excel format with two sheets. The first sheet contains the main data matrix (80×11), while the second provides a codebook explaining the role, unit of measurement, and interpretation of each variable.

4. Differences and Similarities among selected methods

All four models, mentioned in previous section, were developed to extend Data Envelopment Analysis to cases where negative inputs and/or outputs are present. Despite this common motivation, they differ in their theoretical foundations, mathematical formulations, and the way efficiency is computed and interpreted.

A key similarity is that they preserve the enveloping principle of DEA: efficiency is always evaluated relative to a piecewise linear production frontier constructed from observed decision-making units. Moreover, RDM, Two-stage DEA, and SORM are directional or radial models. They rely on a single proportional factor that scales inputs and outputs simultaneously along a chosen direction (Emrouznejad et al., 2010). MSBM, by contrast, belongs to the slack-based family. This method instead of relying on a single radial adjustment, it uses input and output slacks, which measure non-proportional inefficiency in each variable (Tone et al., 2020).

The main differences arise from the structure and treatment of inefficiency. RDM and SORM treat each DMU as a “black box,” while Two-stage DEA explicitly decomposes the production process into two sub-stages (Lychev et al., 2023). This allows the Two-stage DEA to provide stage-specific efficiency scores in addition to the overall measure. In terms of inefficiency measurement, RDM and Two-stage DEA calculate proportional improvements with a single radial factor for each stage (Tavana et al., 2018), while SORM does the same after decomposing negative variables into positive and negative parts (Emrouznejad, Anouze et al., 2010). MSBM, on the other hand, captures inefficiency in a non-radial way, allowing each input and output to adjust differently, with efficiency expressed as a function of the average normalized slacks (Sharp et al., 2007). The strategies for handling negative data are also distinct. RDM introduces an “ideal point” composed of the maximum observed outputs and minimum observed inputs, and defines feasible improvement ranges relative to that point (Portela et al., 2004). Two-stage RDM applies the same logic separately for each stage of the process (Tavana et al., 2018). MSBM normalizes slacks by feasible ranges, thereby ensuring unit invariance and translation invariance (Sharp et al., 2007). SORM avoids both translation

and normalization by splitting each negative variable into its positive and negative parts, and then applying a radial contraction or expansion factor (Cheng et al., 2013).

Another crucial difference is boundedness: while RDM and MSBM rely on feasibility conditions, SORM requires that the models remain bounded. Specifically, the input-oriented version is bounded if at least one input is strictly positive, the output-oriented version is bounded if at least one output is strictly positive, and both are bounded simultaneously if the minimum of these two values is greater than zero. In the Two-stage RDM, boundedness depends on the feasibility of both stage-specific models and the linkage constraint.

Interpretability also varies across models. RDM offers an intuitive interpretation as a proportional “push” toward the ideal point, though results depend on the chosen range direction (Portela et al., 2004). Two-stage RDM extends this by breaking down overall inefficiency into stage-specific components, which provides diagnostic value (Tavana et al., 2018). MSBM is highly interpretable in terms of slacks: the efficiency score can be directly linked to the proportion of inputs to be reduced and outputs to be increased (Zarn, 2023). SORM preserves the familiar feel of classical DEA, through input- or output-orientation, while extending it to cases where data may take negative values.

5. Research results

The comparative application of four DEA models (MSBM, SORM input- and output-oriented, Two-Stage DEA, and RDM) to the same dataset of 80 DMUs highlights differences in the classification of efficiency. The results are summarized in Table 2.

Table 2.

Efficient vs. inefficient DMUs across methods. Own elaboration based on own studies

Method	Number of DMUs	Efficient	Inefficient
MSBM	80	35	45
SORM (Input)	80	42	38
SORM (Output)	80	42	38
Two-Stage DEA	80	25	55
RDM	80	44	36

RDM identifies 44 efficient DMUs and 36 inefficient DMUs. Both the input- and output-oriented versions of SORM identify 42 efficient and 38 inefficient DMUs. MSBM identifies 35 efficient and 45 inefficient DMUs. The Two-Stage DEA model identifies 25 efficient DMUs and 55 inefficient DMUs.

To compare the overlap of efficient sets across methods, the Jaccard similarity index (Fletcher, Islam, 2018) was applied. This measure calculates the size of the intersection of efficient sets between two models divided by the size of their union.

Table 3.*Jaccard similarity between efficient sets. Own elaboration based on own studies*

	MSBM	SORM_in	SORM_out	Two-Stage
MSBM	1.000	0.833	0.833	0.500
SORM_in	0.833	1.000	1.000	0.489
SORM_out	0.833	1.000	1.000	0.489
Two-Stage	0.500	0.489	0.489	1.000

Table 3 presents the Jaccard similarities among MSBM, SORM (input- and output-oriented), and Two-Stage DEA. The Jaccard index between MSBM and SORM equals 0.833 for both orientations. The similarity between MSBM and Two-Stage DEA equals 0.500. The overlap between SORM and Two-Stage DEA equals 0.489 for both orientations. The input- and output-oriented versions of SORM yield identical similarity values.

Rank-order consistency was examined using Spearman rank correlation coefficients to assess the similarity of performance rankings across models.

Table 4.*Spearman correlations of DMU rankings. Own elaboration based on own studies*

	MSBM	SORM_in	SORM_out	Two-Stage
MSBM	1.000	0.938	0.938	0.990
SORM_in	0.938	1.000	0.989	0.925
SORM_out	0.938	0.989	1.000	0.925
Two-Stage	0.990	0.925	0.925	1.000

The rank correlations are uniformly high, all above 0.90, indicating that relative performance orderings are consistent across models. The highest correlation is observed between MSBM and Two-Stage DEA, showing that despite the latter's stricter efficiency criteria, the overall ranking of units remains nearly identical. Similarly, the near-perfect correlation between the two SORM variants confirms that orientation has no practical effect on rankings in this dataset. Preliminary checks for RDM suggest correlations in the range of 0.90 to 0.93 with MSBM and SORM, reinforcing the view that directional measures shift the efficiency threshold but not the relative hierarchy.

6. Discussion

The results demonstrate that efficiency classification in Data Envelopment Analysis is sensitive to the choice of model when non-positive data are present. Although all models were applied to the same dataset using identical inputs and outputs, the number of decision-making units classified as efficient varies substantially across methods. This finding highlights that efficiency, in such settings, is not an intrinsic property of the data alone but depends on the methodological framework used to evaluate it.

The observed differences across models reflect how inefficiency and non-positive values are treated within each DEA extension. Some approaches identify a relatively larger set of efficient units, whereas others impose more restrictive conditions, resulting in smaller efficiency frontiers. These differences indicate that efficiency frontiers are model-dependent rather than invariant. At the same time, the high Spearman rank correlations observed across all model pairs show that relative performance rankings remain largely stable. This suggests that while models differ in where the efficiency cutoff is placed, they tend to order decision-making units in a similar manner. The identical results obtained for the input- and output-oriented versions of the Semi-Oriented Radial Measure (SORM) indicate that orientation has no practical effect on rankings in the analyzed dataset. Furthermore, the substantial overlap between the efficient sets identified by MSBM and SORM, contrasted with the lower overlap involving the Two-Stage DEA model, points to structural differences in how these approaches define and constrain efficiency. Importantly, these differences should not be interpreted as inconsistencies in the results, but rather as natural consequences of distinct assumptions embedded in each model.

These findings extend the existing literature on DEA with non-positive data. Previous studies have primarily focused on proposing individual model extensions or demonstrating their applicability in specific empirical contexts (e.g., Portela et al., 2004; Sharp et al., 2007; Emrouznejad et al., 2010). While this body of work established that negative data can be accommodated within DEA, it offered limited insight into how different extensions compare when applied under identical conditions. The present study contributes by providing a direct, head-to-head comparison of widely used DEA models on the same dataset, thereby isolating the effect of methodological design choices on efficiency classification and ranking.

The results are broadly consistent with earlier findings suggesting that DEA rankings are relatively robust to changes in model specification (Andersen, Petersen, 1993). At the same time, the variation in the number of efficient units aligns with prior observations that alternative treatments of undesirable or non-positive data lead to shifts in the efficiency frontier (Portela et al., 2004; Sharp et al., 2007). What is shown more explicitly in this study is that these two phenomena coexist: substantial differences in frontier membership may occur alongside highly stable rankings. This distinction between ranking stability and frontier sensitivity has received limited explicit attention in previous research.

Taken together, the results confirm the underlying assumption that methodological choices in DEA models handling non-positive data materially affect efficiency outcomes. In particular, the analysis demonstrates that model selection influences which units are labeled efficient, while exerting a more limited influence on relative performance ordering. From a practical perspective, this underscores the importance of explicitly justifying model choice and of complementing point estimates with sensitivity analyses when DEA is applied in the presence of non-positive data.

Future research could extend this comparative framework to empirical datasets from different sectors, examine the sensitivity of results to alternative directional vectors, orientations, or stage weights, and explore hybrid approaches that combine desirable properties of the analyzed models. Such extensions would further clarify the practical implications of model selection and contribute to more transparent and robust applications of DEA in real-world settings.

7. Conclusions

This study set out to identify the main approaches of Data Envelopment Analysis that can handle non-positive data and to show how choosing among them changes measured efficiency as well as rankings. A scan of the literature, combined with expert perspectives, points to four models that are widely used. Although all preserve the general logic of Data Envelopment Analysis, they differ in how they treat translation invariance, the role of directions, the decomposition of processes, and whether inefficiency is captured proportionally or through variable-specific slacks.

When these methods are applied to the same dataset, the set of units labeled efficient changes across models, while the overall ranking of performance remains largely similar. This finding directly confirms that model choice affects efficiency classification even under identical data conditions. In practical terms, the selection of a DEA model influences which decision-making units serve as benchmarks and how inefficiency is assessed relative to the frontier. Consequently, model selection should be explicit and guided by the analytical purpose and empirical context. The Range Directional Model is suitable when directional targets linked to policy or strategy are relevant and translation invariance is required. The Modified Slacks-Based Measure is appropriate when detailed, variable-specific diagnostic information is needed. The Semi-Oriented Radial Measure allows analysts to retain conventional input or output orientations while accommodating non-positive data. Two-Stage DEA models are particularly useful when internal process performance is of interest, albeit at the cost of a stricter efficiency definition.

These conclusions should be interpreted in light of several limitations. The analysis relied on a synthetic dataset, and the expert interviews, while informative, were necessarily limited in number. As a result, the external validity of the findings should be further examined using real-world datasets from different sectors and institutional settings. Nevertheless, the results provide clear lessons for applied efficiency analysis: efficiency outcomes are sensitive to modeling assumptions, and different DEA extensions encode different priorities.

From a broader perspective, this study contributes to the DEA literature by clarifying how alternative treatments of non-positive data translate into differences in efficiency classification and benchmarking outcomes. The findings demonstrate that efficiency assessment is not independent of methodological design choices, and that transparency in model selection is essential, particularly in benchmarking, regulatory, or policy-oriented applications. Future research should build on these results by conducting robustness analyses across datasets, systematically varying model parameters such as directions, orientations, stage weights, and returns to scale, and by integrating sensitivity analysis as a standard component of DEA studies involving non-positive data.

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QUALITY MANAGEMENT METHODS FOR THE EVALUATION OF MANUFACTURING HIGH-STRENGTH STEEL JOINTS

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Purpose: Novelty of the paper is to present the economic aspect of steel braze welding for transportation application. Classic welding process of HSS steel is treated as more difficult and expensive process than braze welding. The aim of the article is to present steps 5 and 6 of 8D analysis, which are used to develop the braze welding process for S 690 QL steel that is less expensive process than welding.

Design/methodology/approach: Quality management methods (8D method, 5 WHY) were used to identify nonconformities, determine their causes and reduce production costs. To improve the quality of the production process and eliminate the causes of existing material incompatibility, it was found that a new process of material bonding should be used. Various filler materials were used. Main parameters of the braze welding process were tested and then the quality of the obtained joint was checked.

Findings: Quality management methods indicated that a viable solution to the problem required the development of a new process and the use of other electrode wire materials. In step 6 of the 8D analysis, the proper filler materials and parameters of the process were proposed.

Research limitations/implications: It is possible to realize the process without expensive preheating. The most favorable process parameters have been discovered.

Practical implications: The proposed process innovation will result in savings of production, and the presented solution will contribute to the improvement of the joint manufacturing process.

Social implications: Braze welding process allows for energy savings.

Originality/value: It is to propose a new solution in automotive and rail transport. The article is especially addressed to the elements of the various means of transport.

Keywords: process improvement, quality management methods, production savings, transport, braze welding.

Category of paper: Research paper.

1. Introduction

One of the reported problems with the production of connectors by means of transport is the high cost of the manufacturing process compared to the safe operation time of the weld. To solve the problem effectively, it was necessary to determine the causes of the problem, propose a way to reduce the cost, and implement corrective actions. 8D method is a team-based problem-solving approach/process of 8 critical steps with a focus on actions to contain, correct and prevent recurrence of the problem (Lubas Wahyudi, Wulandari, 2020). The authors of the article used a modified 8D method to solve the problem, but the article presents only the 6 steps.

First step is establishing a team consisting of material science, means of transport and quality management experts. The team have a good knowledge of the product (joints) and processes (welding), and it has adequate capability to introduce proper solutions to the identified problem.

In the second step, the team described the problem in detail. The cost drivers were identified (material purchase costs, equipment use, personnel costs, etc.) and it was concluded that the greatest savings could be achieved through material and technological changes. The current manufacturing process generates almost 75% of the final product costs, which, according to Pareto-Lorenz analysis, is the main problem. It was assumed that shortening the process (and thus reducing staff time, machine use time, etc.) should translate into lower costs. During the brainstorming session, some proposals were rejected, such as reducing staff numbers, which, according to the authors, could result in employee overload and ultimately lower product quality. It was also analyzed whether there were any errors in the process, generating unnecessary costs and affecting the service life of the final material. Such causes include, for example, improper storage of materials, errors in instructions. It has been stated that to truly eliminate a problem, it is needed to identify its true cause. This is not an easy step, so it is important to work as a team and look at the problem from different perspectives. At this stage of the project, quality tools such as Ishikawa analysis and the 5 Why method were used (Wirawan, Minto, 2021). An example of the 5 WHY analysis is presented in Fig. 1.

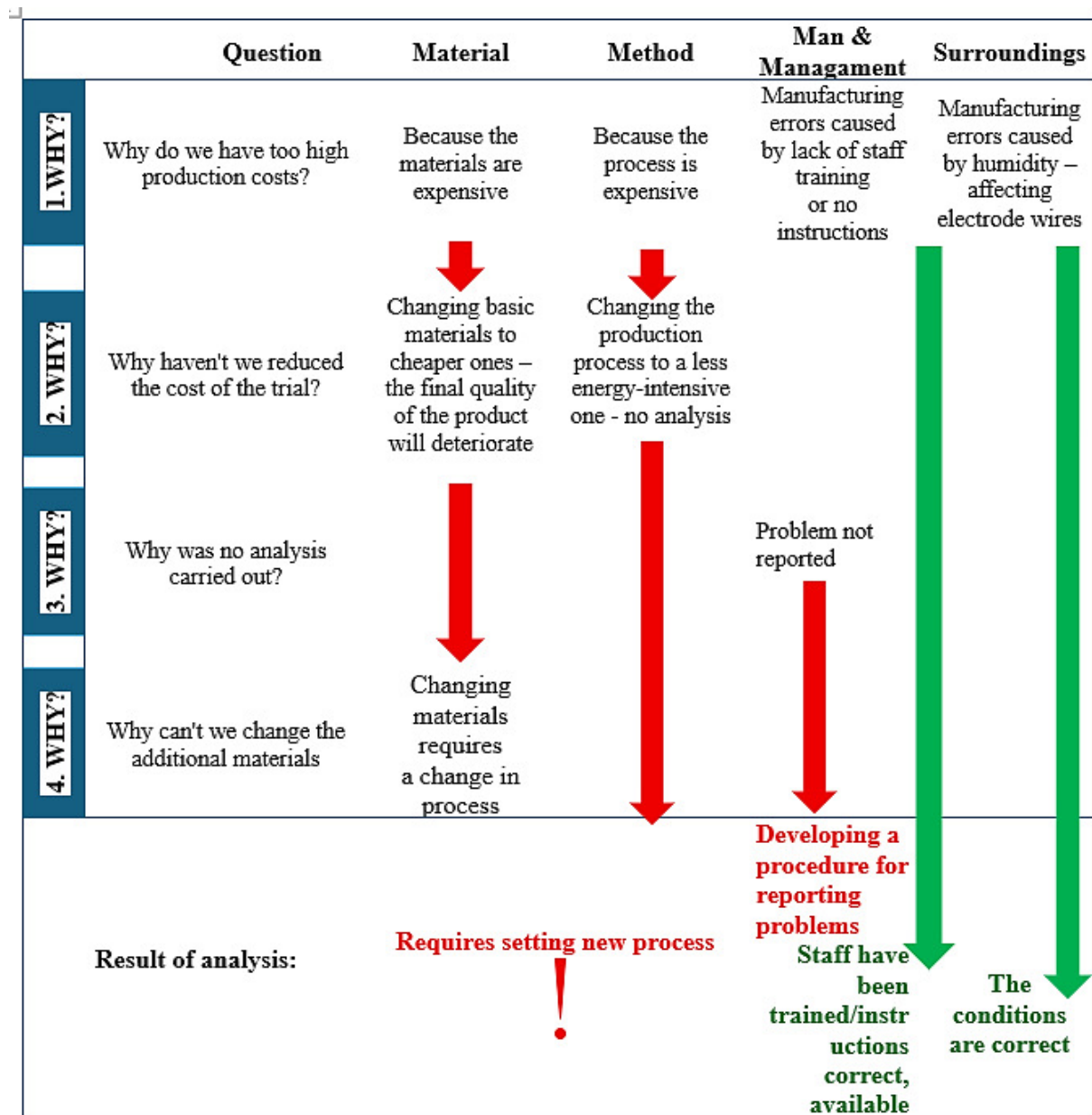


Figure1. Analysis 5 WHY.

The 5 Why analysis showed that a new process should be developed that uses other electrode wire materials and develop reporting procedures.

At these stages of the project (step 5-6), the authors of the paper developed a new process using different types of electrode wires. This part of the research as the main design achievement is widely described in the next chapters of the article. The solution required the application of extensive material expertise, knowledge of material testing methods, their selection and evaluation of the quality of joints obtained in the braze-welding process.

2. Step 5 and 6 of modified 8D analysis – braze welding process

Braze welding is mainly used in situations where it is important to obtain tightness and precision of the connection, and tensile strength is less important. Braze welding is mainly used in situations where it is important to obtain tightness and precision of the connection, and tensile strength is less important (Li, Hou, Tian, Hong, Nord, Rohde, 2022). This part of examination focuses on the welding of HSS steels, which are not easily welded for various reasons. One of the most important factors impairing weldability is the dominant martensitic structure of HSS steel, which promotes weld cracking (Punzel, Hugger, Dörringer, Dinkelbach, Bürger, 2020). Depending on the thickness of the material being welded, various process parameters are selected, such as welding speed, current intensity, arc voltage, and shielding gas flow rate. In conventional welding, costly preheating is often used. In principle, separate tests should be conducted for each thickness of HSS steel structure to determine the feasibility of achieving a safe joint and selecting the most appropriate parameters, which is quite tedious (Lee, Jeong, Lee, Fujii, Shin, Lee, 2023). Achieving high tensile strength is not essential for all joints, but universal connection of structural elements is. A significant number of these types of joints are used in the construction of transportation vehicles. This article analyzes the weldability of S690 QL steel, a representative of the HSS group of materials. The appropriate electrode wire was selected, and precise process parameters were established, which can be used for various sheets, as the sheets are not melted during the joining process. A literature review found no guidance on selecting electrode wires or process parameters. The classical welding process for HSS steels is much more widely understood (Mannucci, Tomashchuk, Vignal, Sallamand, Duband, 2018).

Economic factors play an important role: brazing is generally much cheaper than conventional welding for a variety of reasons. The brazing process is economically more viable than conventional welding for many reasons. The complete elimination of preheating is crucial. Furthermore, operating time is shorter, labor is reduced, and energy consumption is lower (Beck, Bantel, Boley, Bergmann, 2021). Brazing equipment is lighter and cheaper. Post-processing of the braze joint is usually unnecessary (Kumar, Arya, Palani, Madhukar, Sathiaraj, Patel, 2022). Material consumption is generally much lower (Sairam, Balaji, Menon, Manikandan, 2023). The authors also analyzed the braze welding process for environmental reasons, which is related to energy savings and lower material consumption.

2.1. Materials

For braze welding of S690 QL steel 3 various electrode wires were proposed. They were used as a shielding gas pure argon (without mixture with CO₂). The use of high purity argons is important to avoid braze welding incompatibilities. Helium is sometimes occasionally recommended to do shielding argon gas mixture. In the braze welding process, it was decided

to realize process without preheating. The thickness of elements was 2 mm. Table 1 shows the mechanical properties of the S690 QL.

Table 1.
Tensile strength of tested material

Steel	YS MPa	UTS, MPa	A5, %
S690 QL	690	970	14

The table data shows that material has high tensile strength that depends on chemical composition (Table 2).

Table 2.
Chemical composition of S690 QL [6]

Steel	C	Si	Mn	P	S	Al	Cr	Cu	Mo	Nb	Ni	Ti	V	B
S690 QL	0.21	0.8	1.7	0.025	0.015	0.01	1.55	0.5	0.7	0.06	2.1	0.05	0.12	0.005

The table data shows that material has high amount of Ti, that has influence on mechanical properties of the material. Chemical composition of electrode wire is given in Table 3.

Table 3.
Chemical composition of wires for braze welding

Wires	Si, %	Mn, %	Fe, %	Zn, %	Ni, %	Cu, %
CuSi2	1.9	0.4	0.3	0.1	0.03	bal
CuSi3	2.9	1.2	0.5	0.1	0.05	bal
CuSi3Mn1	3.9	1.5	0.4	0.2	0.5	bal

Before starting to make joints, no chamfering was performed. The braze welding parameters were as follows:

- diameter of the electrode wire: 1 mm,
- arc voltage: 18 V,
- welding current was varied twice: 150 A, 170 A,
- welding speed was varied twice: 325 mm/min, 355 mm/min,
- shielding gas flow: 14 l/min
- the nature of the weld: single pass.

2.2.Methods

Brazed joints were created according to the instructions in the previous chapter. The quality of the joints was then checked using NDT (non-destructive testing) and DT (destructive testing) methods. Mainly, VT – visual test (using EN ISO-17638 standard) and TP –penetration test was carried out. Penetrant was a standard DBR, cleaner was BRE-S, developer was BEA. Time of penetration was 35 min. After NDT, some destructive tests were realized:

- tensile strength, PN-EN ISO 6892-1 from 2020,
- bending test, PN-EN ISO 5173.

2.3. Results and discussion

Braze welding joints were made using 3 various electrode wires (CuSi2, CuSi3 and CuSi3Mn1), with 2 various braze welding current (150 A, 170 A) and with 2 various welding speed (325 mm/min, 355 mm/min). Braze welding was realized without heat treatment. Following all the experiments, 12 different samples were made (Table 4).

Table 4.
Samples designations

Sample	Current, A	Electrode wire	Welding speed mm/min
U1	150	CuSi2	325
U2	150	CuSi3	325
U3	150	CuSi3Mn1	325
U4	170	CuSi2	325
U5	170	CuSi3	325
U6	170	CuSi3Mn1	325
U7	150	CuSi2	355
U8	150	CuSi3	355
U9	150	CuSi3Mn1	355
U10	170	CuSi2	355
U11	170	CuSi3	355
U12	170	CuSi3Mn1	355

Only 6 samples marked as U2, U5, U6, U8, U10, U11) were free from braze welding incompatibilities or defects (table columns are marked in green), but also 6 samples were treated as defective or unacceptable (table column marked in pink). Detailed observations and comments of the VT (visual test) and TP (penetration tests) results are presented in Table 5.

Table 5.
NDT results for tested braze welds

Sample	Observation
U1	Small cracking in braze weld
U2	Correct braze weld
U3	Correct braze weld
U4	Blisters and porosity
U5	Correct braze weld
U6	Correct braze weld
U7	Small cracking in braze weld
U8	Small cracking in HAZ
U9	Blisters and porosity
U10	Correct braze weld
U11	Correct braze weld
U12	Blisters and porosity

Generally, it was found that the choice of current and proper selecting of electrode wire is more important factor. The braze welding current should be at the level of 170 A. It was clearly noticed that the best electrode wire for brazing is CuSi3. Based on NDT, it can also be suggested that a faster braze welding speed might be more suitable for joining the S690QL steel. The next part of the investigation was to check the tensile strength of braze welds. Only those samples that had positive results in NDT tests were chosen to the account (U2, U5, U6, U8, U10, U11). Table 6 presents the tensile strength (UTS) of the braze weld.

Table 6.

Tensile strength of the dissimilar braze weld

Sample	Electrode wire	UTS [MPa]
U2	CuSi3	131
U5	CuSi3	141
U6	CuSi3Mn1	123
U8	CuSi3	141
U10	CuSi2	136
U11	CuSi3	152

The data from Table 6 allowed us to draw the conclusion that tensile strength of all tested joints was over 120 MPa. The analysis of Table 6 proves that the braze welds made with CuSi3 electrode wire have higher tensile strength. Next, a bending test was realized out to find the detachment angle. A bending test was carried out at ambient temperature. The results of bending test are demonstrated in Table 7.

Table 7.

Bending test of braze weld

Tensile strength of the dissimilar braze weld

Sample	Electrode wire	Detachment angle
U2	CuSi3	30
U5	CuSi3	35
U6	CuSi3Mn1	30
U8	CuSi3	35
U10	CuSi2	30
U11	CuSi3	40

The angle at which the joint deboned was the largest for sample U5, U8, U11. This confirms that the CuSi3 electrode wire is the most suitable for brazing S 690QL steel.

3. Summary

The article presents the possibilities of using quality management methods to identify the problem, determine its causes and develop a solution by experts. Application of the 8D method combined with brainstorming and the analysis of the 5 WHYs made it possible to identify areas

that needed to be modified. The results of the analysis indicated the need to develop procedures for reporting problems, as well as to improve and modify the manufacturing process.

As a result of the work in this article, a new solution for the production process of welded joints for transport needs was created. This article presents the possibility of economic joining S 690QL steel without preheating. Preheating treats as expensive procedure due to the consumption of energy and propane preheating, gas for heating. The newly developed method allows for production savings. The properties of braze welding were tested using both non-destructive and destructive methods. The joints, despite the cheaper production method, are characterized by excellent properties. The possibility of obtaining brazed joints using three different copper-based electrode wires was carefully analyzed. Additionally, a decision was made to select different process parameters, which allowed us to produce 12 different samples for testing and joint quality assessment. Based on the braze welding study it was possible to assume that:

1. Braze welding of S 690QL steel leads to process savings in relation to joints made in the classical welding process.
2. Braze welding parameters (composition of electrode wires, braze welding current and speed) should be selected with great sensitivity.
3. The best mechanical properties of braze welds were obtained when the electrode wire CuSi3 was selected for the process.

In the next steps, reporting procedures should be developed, as indicated by the results of the 5 WHY method and the implementation and workplace procedures for the newly developed process.

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BUILDING COMPETITIVE ADVANTAGE OF PUBLIC UNIVERSITIES IN NON-METROPOLITAN CITIES UNDER BANI CONDITIONS

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Purpose: This article identifies sources of competitive advantage of public universities located in non-metropolitan Polish cities under BANI conditions, using the LTR analytical framework (location, technology, relations) as an interpretative tool for understanding institutional resilience in response to environmental uncertainty.

Design/methodology/approach: A qualitative, document-based multiple case study analysis examines four public universities located in Piotrków Trybunalski, Kalisz, Słupsk, and Siedlce. The LTR framework is applied to extract strategic priorities from institutional and municipal development documents, supplemented by an international analytical counterpoint to assess the scalability of the framework.

Findings: The analysis reveals that non-metropolitan universities follow a defensive-adaptive strategy rather than replicating metropolitan patterns. Through the LTR lens, institutional resilience is built via Location, which stabilizes well-being and mitigates anxiety (Anxious); Technology, which enables organizational agility and navigation of non-linear challenges (Non-linear); and Relations, which anchor universities in their local ecosystems and address incomprehensible complexity (Incomprehensible). The synergy of these three dimensions contributes to gaining a competitive advantage, buffering universities against organizational brittleness (Brittle).

Research limitations/implications: The qualitative focus on declarative strategic documents—adopted intentionally—limits the scope for generalization. Future research should quantitatively examine the relationship between LTR synergies and performance indicators such as graduate career tracking (ELA) and regional economic effects.

Practical implications: The LTR analytical framework offers a diagnostic tool for policymakers, indicating that regional universities should prioritize contextual specialization over the mechanical imitation of metropolitan development models.

Social implications: As anchor institutions, public universities in non-metropolitan cities play a critical role in regional resilience, acting as buffers against brain drain and long-term regional weakening in a BANI environment.

Originality/value: The paper introduces an original LTR analytical framework to the study of regional public universities under BANI conditions, shifting analytical attention from organizational scale to strategic synergy.

Keywords: Competitive advantage, Public universities, BANI, Non-metropolitan cities, LTR analytical framework.

Category of the paper: Research paper.

1. Introduction

Contemporary higher education operates under conditions of dynamic, unpredictable, and difficult-to-interpret change, commonly described through the concept of the BANI world (Brittle, Anxious, Non-linear, Incomprehensible) (Le Roux, Sutton, 2022). This framework highlights profound disruptions to stability, increasing uncertainty, and the growing complexity of processes affecting institutional functioning. For public universities, these conditions necessitate the development of new adaptive capacities, including organizational flexibility and the ability to identify and leverage alternative sources of competitive advantage.

Existing research on the competitiveness of higher education institutions in Poland has focused primarily on large academic centers located in metropolitan cities such as Warsaw, Kraków, Wrocław, Poznań, and Gdańsk, or on large non-metropolitan cities (e.g., Olsztyn, Opole, Zielona Góra, Bielsko-Biała, Radom, Tarnów, Włocławek) (Rokita-Poskart, 2015). Significantly less attention has been devoted to public universities operating in medium-sized non-metropolitan cities—understood here as cities with populations of up to 100,000—despite the fact that these institutions perform important social, economic, and cultural functions and often serve as key anchor institutions for local development (Harris, Holley, 2016; O’Farrell et al., 2022; Craig, 2025).

Although previous studies have analyzed the role of academic functions in local development strategies in a medium-sized city (Kalisz) and a small city (Nysa) (Rokita-Poskart, 2015), as well as a case study of Grudziądz, a city without a public university (Nalaskowski, Dejna, 2020), these analyses focused primarily on urban strategies and higher education institutions in general, rather than on public universities and their institutional strategies. Furthermore, these studies did not take into account the conditions of the BANI world, in which smaller, more cohesive urban systems may have clear advantages in terms of stability, quality of life, and greater capacity for coordinated action.

At the same time, non-metropolitan cities and the universities operating within them face a range of structural challenges, including limited labor markets, restricted access to resources, weaker positions in national and international rankings, and difficulties in attracting academic staff. In the context of declining student demand and intensifying inter-university competition, identifying sources of competitive advantage that are not derived from metropolitan status has become a critical strategic task.

The higher education literature increasingly emphasizes the importance of universities’ adaptive capacities, manifested in organizational agility (Menon, Suresh, 2020), the development of dynamic capabilities (Heaton et al., 2019; Guerrero, Menter, 2024; Liao, Suprpto, 2024), selective digital transformation (Mohamed Hashim et al., 2022; Alenezi, Akour, 2023), and relational collaboration with the socio-economic environment (Knop, Papież-Pawelczak, 2023). However, these approaches are rarely subjected to empirical analysis

in relation to public universities operating outside metropolitan centers, particularly under conditions of uncertainty and non-linearity characteristic of the BANI world.

This article seeks to demonstrate that a key factor in building competitive advantage for public universities located in non-metropolitan cities is the synergistic use of three interrelated dimensions that gain particular significance under BANI conditions: Location (L), Technology (T), and Relations (R).

The purpose of this study is to analyze the ways in which public universities located in non-metropolitan cities can build competitive advantage under BANI conditions, with particular emphasis on the synergy among these three dimensions. The article employs an author's original analytical framework of competitive advantage for non-metropolitan universities that integrates internal organizational capabilities with external relationships embedded in the urban environment. As points of reference, the University of Warsaw (as a national analytical counterpoint) and the University of Cambridge (as a global analytical counterpoint of a university located in a medium-scale university city) are used, enabling comparison across national, European, and global dimensions.

2. Literature Review

2.1. The BANI World: The Concept and Its Relevance to Higher Education

The concept of the BANI world, proposed by Jamais Cascio in 2020 (Cascio, 2020), represents both an extension of and an analytical correction to the VUCA model. Cascio argues that VUCA no longer adequately captures the nature of contemporary social, economic, and technological conditions, the intensification of which has become particularly evident in recent years (Hrynychak, Motuzka, 2023). This is especially true in the case of global disruptions such as the COVID-19 pandemic, supply chain interruptions, accelerated digitalization, and the escalation of socio-political tensions. BANI thus characterizes reality as Brittle (B), Anxious (A), Non-linear (N), and Incomprehensible (I), necessitating a redefinition of traditional models of organizational management.

Unlike the VUCA framework, which focuses primarily on the analysis of current phenomena, the BANI concept emphasizes the future-oriented nature of uncertainty and the multidimensionality of ongoing processes (Miernik, 2023). Introducing this perspective reshapes approaches to systemic resilience, organizational flexibility, and adaptive capacity—issues that are particularly salient in the higher education sector.

Polish higher education experiences all components of the BANI world, with particularly strong effects on regional universities. Institutions operating in non-metropolitan cities exhibit high sensitivity to system brittleness (B) resulting from limited demographic bases, as well as

anxiety (A) driven by lower brand recognition and the heterogeneous conditions of local labor markets. At the same time, conditions of non-linearity (N) in development processes, regional universities may mitigate through selective digitalization, which reduces the negative effects of peripherality. In turn, the incomprehensibility (I) of complex market relationships may be reduced by their stronger social embeddedness in the ecosystems, in which they function. The BANI framework provides a useful interpretive lens for analyzing development strategies of universities located in non-metropolitan cities.

2.2. Non-Metropolitan Cities as the Institutional Environment of Universities

Analyzing the development conditions of public entities, including universities, requires a precise definition of their operating environment, which in the case of smaller urban centers differs fundamentally from that of large metropolitan agglomerations. Contemporary scholarship has increasingly moved away from strictly administrative boundary definitions in favor of a functional approach. A key concept in this regard is the Functional Urban Area (FUA), which comprises the urban center and its commuting zone, where—according to international standards—at least 15% of the working population commutes to the city (Dijkstra et al., 2019; EUROSTAT, 2017). This approach makes it possible to capture the actual spatial reach of a city's influence beyond its formal administrative borders.

Despite ongoing efforts toward methodological harmonization, international comparisons remain challenging due to differences in demographic and administrative criteria (United Nations, 2025). Institutions such as the OECD and Eurostat classify urban areas primarily on the basis of population size, distinguishing between large metropolitan areas, metropolitan areas, medium-sized urban areas, and small urban areas (OECD, 2014), a distinction that is also reflected in U.S. classification systems (NCES, 2023). In the Polish context, a four-tier typology is commonly applied, differentiating between small, medium-sized, large cities, and metropolitan areas, with the metropolitan threshold typically set at populations above 500,000 (Magazyn Miasta, 2025; Rogalińska, 2024).

For the purposes of this study, the category of “non-metropolitan cities” is defined broadly to include urban centers with county-level status whose populations fall below the metropolitan threshold of 500,000. However, in line with the research objective, the analysis focuses on a specific subgroup within this category—medium-sized cities with populations of up to 100,000. These cities function as local service and administrative centers but lack the infrastructural complexity and agglomeration advantages characteristic of major growth poles. In Poland, their development trajectories are strongly shaped by unfavorable demographic trends, including depopulation and brain drain, as well as limited access to investment capital (Rogalińska, 2024).

Differences between metropolitan and non-metropolitan cities are also evident in local labor markets. Market analyses indicate that while metropolitan areas are characterized by very low unemployment rates, strong wage pressure, and intense competition for workers, smaller urban

centers tend to exhibit more stable and differentiated labor market conditions (Business Insider, 2025).

From the perspective of university strategic management, operating in such an environment creates a unique contextual setting that, under BANI conditions (Brittle, Anxious, Non-linear, Incomprehensible), takes on a dual character. On the one hand, the smaller scale of the city may generate structural brittleness, manifested in a stronger dependence of universities on the financial condition of local governments and businesses. On the other hand, this environment may help reduce incomprehensibility as it facilitates the development of more durable, trust-based stakeholder relationships—relationships that are considerably more difficult to establish in anonymous metropolitan contexts. Consequently, non-metropolitan status should not be viewed solely as a resource deficit but rather as a distinct contextual condition that requires alternative models for building competitive advantage by public universities.

2.3. The Higher Education System in Poland and Its Spatial Differentiation

The higher education system in Poland is characterized by a high degree of institutional and spatial differentiation. According to data from Statistics Poland (GUS, 2025), more than 352 higher education institutions operated nationwide. A key distinction within the system is between academic universities and professionally oriented institutions, the latter focusing primarily on teaching activities.

As of July 7, 2025, the Polish public higher education sector comprised 103 institutions, of which 64 were supervised by the minister responsible for higher education, while the remaining institutions were overseen by sectoral ministries, including culture, health, and national defense (RADON, 2025). An analysis of their spatial distribution reveals a clear process of metropolitan concentration: among academic universities, only four institutions operate in medium-sized cities, whereas the remaining 61 are located in major urban centers (MEN, 2025).

This spatial distribution also affects access to educational offerings. The highest concentration of study programs is observed in Warsaw (1,312 programs), followed by Kraków (996), Poznań (662), Wrocław (650), Lublin (510), Łódź (492), Szczecin (405), and Gdańsk (396) (MEN, 2025). This pattern reflects the historical centralization of research and academic activity, which for decades has been concentrated in the largest metropolitan areas.

The concentration of academic programs in major metropolitan centers is also mirrored in the higher academic potential of these cities, as measured, for example, by the City Academic Index developed by the Polish Economic Institute (PIE, 2023). Strong universities contribute to population growth, strengthen human capital, and attract investment, while simultaneously benefiting from the development of infrastructure and labor markets. These relationships are bidirectional: cities with higher levels of socio-economic development are more likely to host universities ranked highly in national and international assessments, while dynamic universities further stimulate urban growth (Dębkowska et al., 2023; Kozień, 2021).

Against this background, public academic institutions located outside major metropolitan centers face particularly complex institutional and spatial operating conditions. This context forms the empirical basis of the study. The analysis focuses on four public academic institutions supervised by the minister responsible for higher education and science and located in non-metropolitan cities, which constitute the entire population of such institutions in Poland.

As the literature highlights, these universities operate under conditions that can be interpreted through the BANI framework; however, previous studies have addressed these challenges in a rather fragmented manner. To address this research gap, the study adopts a conceptual model based on three interrelated dimensions of competitive advantage: location, technology, and relations (LTR).

3. Methods

3.1. The LTR Analytical Framework and Variable Operationalization

To diagnose the competitive position of the units under study, an original LTR analytical framework was employed, specifically adapted to the characteristics of non-metropolitan centers. At its core, the framework is built around a conceptual model which posits that competitive advantage (CA) under conditions of uncertainty (BANI) is the outcome of the synergy among three dimensions: Locational (L), Technological (T), and Relational (R). This relationship is expressed heuristically as a multiplicative conceptual model, allowing for the recognition of the complementary character of the L, T, and R dimensions (Figure 1):

$$CA = L \cdot T \cdot R \quad (1)$$

(as opposed to $CA = L + T + R$)

This conceptual structure assumes that in non-metropolitan contexts, a critical deficit in one area (e.g., lack of digitalization or isolation from the surrounding environment) cannot be fully compensated by a surplus in another, resulting in a loss of competitive capability. The equation serves a heuristic and conceptual purpose and does not represent a quantitative estimation.

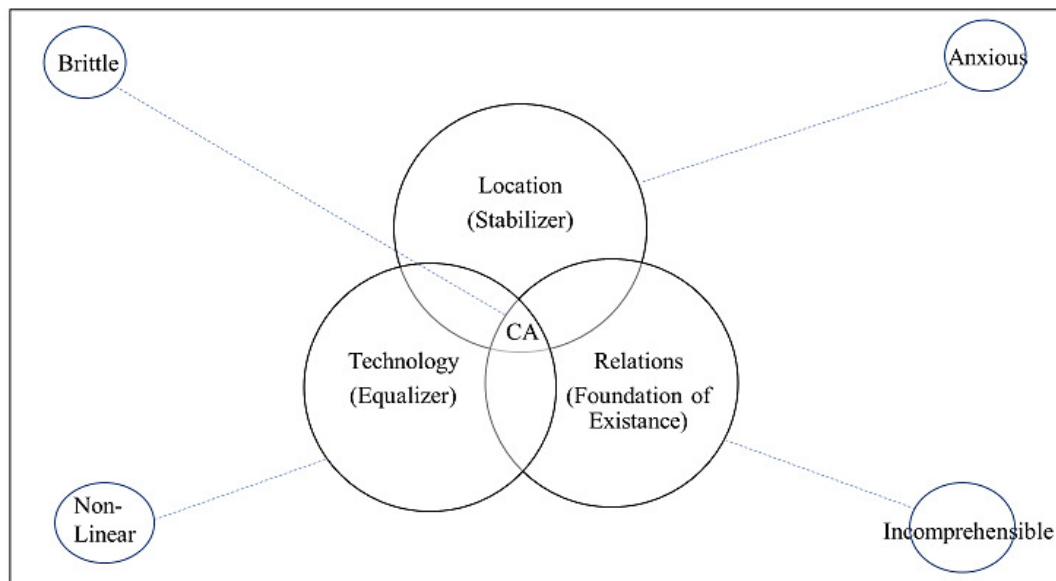


Figure 1. The LTR conceptual model of synergistic competitive advantage as a response to BANI – related challenges.

Source: own study.

The framework's variables were operationalized as follows (Table 1):

Locational Dimension (L) – grounded in J. Barney's (1991) Resource-Based View (RBV) – was defined in a dual perspective as the university's internal infrastructure (tangible resources, quality of study environment: campuses, dormitories) and the surrounding environment's potential (quality of life, safety, cost of living).

Technological Dimension (T) – based on D. Teece's (1997, 2007) Dynamic Capabilities framework – is understood as the level of digital maturity of both the city (Smart City) and the university (e-services, hybrid education), as well as the ability to reconfigure digital resources by both the city and the university.

Relational Dimension (R) – drawing on Network Theory (Burt, 1992) and social capital concepts (Coleman, 1988; Putnam, 2000) – is defined as the intensity and quality of collaboration with local stakeholders (municipal authorities, businesses, NGOs), creating shared interpretive frameworks in the city-university/university-city relationship.

Table 1.

Characteristics of the Three Dimensions of the LTR Analytical Framework under BANI Conditions

Dimension	Description	Factors	Role	BANI Elements
Locational	Quality of life – environmental stability	Moderate cost of living, proximity to nature, slower pace of life, low "information noise," lower ecosystem complexity	Compensates for non-metropolitan status; enhances attractiveness for students and faculty seeking stability and high quality of life	Reduces anxiety (A) and serves as a stabilizer in the face of environmental brittleness (B)

Cont. table 1.

Technological	Digitalization – organizational agility	Adaptability, capacity to leverage mature digital systems, hybrid learning models, automation of administrative and student processes	Mitigates geographical distance from metropolitan centers; strengthens adaptability and transformative capabilities	Key for responding to process non-linearity (N) and building resilience to environmental brittleness (B)
Relational	University–city / city–university collaboration – creating shared sense-making structures	Strategic partnerships, joint infrastructural and cultural projects, co-development of study programs aligned with local needs, investments in academic environment attractiveness, coordination among local actors	Builds a local knowledge ecosystem; enhances resilience through networking; fosters a university identity rooted in the city	Critical for managing environmental incomprehensibility (I) and environmental brittleness (B)

Source: own study.

While each dimension of the LTR framework addresses specific sources of uncertainty under BANl conditions, it is their synergistic interaction that generates competitive advantage, which functions as a buffering mechanism against organizational brittleness rather than as a simple sum of individual effects.

The conceptual model defined above constituted the core of the analytical framework used to interpret the collected empirical data and structure the results of the present study.

3.2. Methodological Assumptions

The study was conducted using a qualitative document-based multiple case study, drawing on strategic documents (development strategies) from four public academic institutions located in non-metropolitan cities: Piotrków Academy in Piotrków Trybunalski, Kalisz University in Kalisz, the Pomeranian University in Słupsk, and the University of Siedlce. The study adopted an exhaustive sampling strategy regarding public academic universities located in non-metropolitan centers.

The content analysis of these documents was structured around three categories derived from the author's LTR analytical framework, which served as the interpretive matrix for the study:

L (Locational dimension: location and quality of life/study environment).

T (Technological dimension: technology and digitalization).

R (Relational dimension: city–university / university–city relations).

The LTR analytical framework was employed as a tool to operationalize the key dimensions that, according to the author, influence the development of universities in non-metropolitan cities. This research procedure enabled a systematic comparison of the content of university and city strategies, as well as the identification of patterns in their collaboration, developmental priorities, and approaches to building competitive advantage.

To broaden the contextual scope, an additional comparative dimension was introduced, including the University of Cambridge (UK) as a model example of a non-metropolitan academic ecosystem with global reach, and the University of Warsaw as a reference point for universities operating in metropolitan contexts.

It should be emphasized that the University of Cambridge was not employed in this study as a benchmark in terms of financial scale or academic prestige, but rather as a paradigmatic example of functional integration between a university and a mid-sized city. It provides justification for the assertion that non-metropolitan location can serve as a foundation for global competitiveness if the synergy mechanisms (L·T·R) are fully leveraged.

The multiple-case study approach allowed for the comparison of strategies of universities located in non-metropolitan cities with selected national and international counterpoints. The application of the LTR analytical framework enabled the systematic identification of similarities, differences, and developmental conditions arising from locational, technological, and institutional relational factors, as well as their potential to foster growth in a BANI world.

4. Results

4.1. Characteristics of Selected Non-Metropolitan Cities in Poland

The cities hosting the selected universities occupied diverse positions in the 2018 ranking of county-level cities published by *Polityka*. The ranking highlights significant disparities in quality of life across Poland – from the highest-rated cities, such as Sopot, Warsaw, and Kraków, to considerably lower scores for medium-sized cities, including Kalisz, Słupsk, Piotrków Trybunalski, and Siedlce. This underscores the necessity for these centers to build competitive advantage from a so-called “low starting point” (Figure 2).

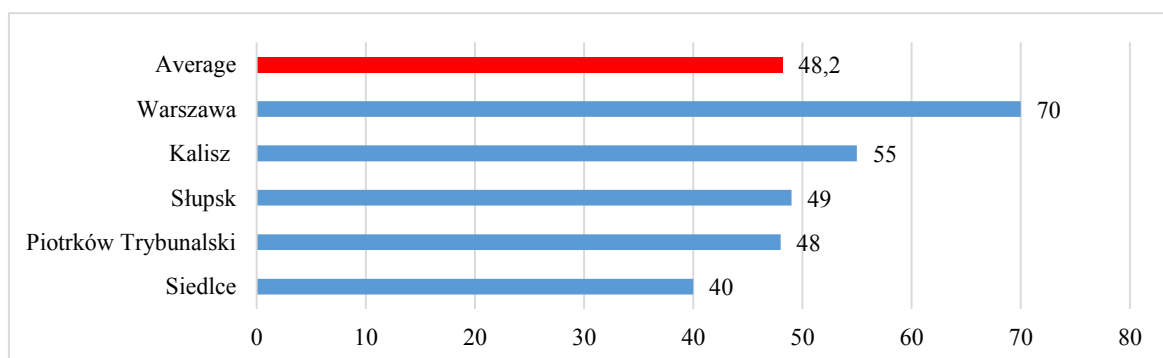


Figure 2. Overall Quality of Life Index for selected county-level cities in 2018.

Source: own study based on the Ranking miast powiatowych według poszczególnych kategorii, 2018: <https://www.polityka.pl/niezbednik/rankingmiast/1597033,1,ranking-miast-powiatowych-wg-poszczegolnych-kategorii.read?categoryId=1>

In the context of the development of higher education institutions, both a city's location and its socio-economic potential are of critical importance. An analysis of four Polish county-level cities—Piotrków Trybunalski, Kalisz, Słupsk, and Siedlce—demonstrates how local government authorities conceptualize the role of universities. Based on the dominant cooperation mechanisms identified within strategic planning documents and following the adopted methodology, four specific relationship models were distinguished and categorized according to the dimensions of the LTR framework:

1. Piotrków Trybunalski – The Economic Niche Support Model

The city has a population of 66,211 (Polska w liczbach, 2025) and serves as a subregional transport hub within the Łódź Voivodeship. It leverages its strategic location at the intersection of the A1 motorway and the S8 express road, as well as its proximity to the Łódź airport (Urząd Miasta Piotrków Trybunalski, 2022). Analysis of strategic documents indicates a focus on economic niches, as reflected in the dimensions of the LTR framework:

Location (L): Within the adopted categorization, this area includes actions aimed at compensating for "big-city deficits" through revitalization (Goal 1.4) and the development of "blue-green infrastructure", such as the revitalization of the Bugaj reservoir area (Goal 2.3). These efforts are interpreted as an attempt to enhance the city's attractiveness as a place of residence for both academic staff and students.

Technology (T): Analysis of this dimension reveals a focus on energy transformation and the circular economy (Goal 2.1). A key element is the functioning of the Digitization and Organizational Supervision Office, alongside the implementation of specific tools like the E-BOM mobile app and local IT support points (Urząd Miasta Piotrków Trybunalski, 2022). This creates the necessary infrastructure for implementation-oriented research.

Relations (R): A rare feature identified in local government documents is the direct inclusion of university support within operational goals (Goal 3.1: "Support for the development of higher education institutions"), specifically regarding the transformation of the Piotrków Academy. This is complemented by plans to establish a business incubator supporting R&D initiatives (Goal 2.1).

The strategy of Piotrków Trybunalski seeks to reduce brittleness (B) by closely linking academic functions with economic priorities.

2. Kalisz – The Urban-Academic Symbiosis Model

Kalisz, with 92,533 residents (Polska w liczbach, 2025), is strategically located between the metropolises of Łódź, Wrocław, and Poznań. The city represents a model characterized by the full incorporation of academic goals into the development strategy (Urząd Miasta Kalisza, 2022), driven by the strong potential of local institutions (Kalisz University, Adam Mickiewicz University in Poznań – Kalisz Branch, Uniformed Services Campus of the University of Justice).

Location (L): The strategy implements the "compact city" concept, with a particular emphasis on the "Kalisz for Youth" program, which provides students and graduates with access to municipal housing (Goal 2.5). Within the LTR framework, this is interpreted as a response to student anxiety (A) regarding the high cost of living in metropolises.

Technology (T): Development in this area is based on the Smart City concept, including the introduction of e-service platforms and enhancing the digital competencies of municipal officials. The focus on energy efficiency (Goal 7.1) provides a modern environment for university operations.

Relations (R): The core element is the explicitly defined Operational Goal 4.1: "Academic Kalisz," along with projects such as "High Quality of Education." The analysis identifies this as evidence of treating the university as a primary partner in urban transformation and a provider of human capital for investments (Goal 5.1).

The Kalisz model is based on symbiosis: the city provides modern infrastructure and living conditions, while the university provides human capital.

3. Słupsk – The Quality-of-Life Compensation Strategy

Located in the Pomeranian Voivodeship, Słupsk has 85,135 residents (Polska w liczbach, 2025) and serves as a regional center for education and services. The city's strategy (Urząd Miasta Słupsk, 2022) is based on a compensation mechanism—deficits in metropolitan infrastructure are offset by "soft" resources.

Location (L): The identified priority is resident retention through housing development (Direction 2.3) and a rich leisure offer (Direction 1.8). These actions aim to build an attractive "Student Lifestyle" to counter the gravitational pull of larger metropolises.

Technology (T): This dimension is pursued through the goal of "energy independence" (Direction 4.3), which serves as a direct response to the non-linearity (N) of energy prices and supplies in a BANI world. Simultaneously, the modernization and digitization of administrative services (Direction 1.5) elevate the standard of service for student-residents.

Relations (R): The Pomeranian University in Słupsk is treated as a central urban-forming entity. In this dimension, the city positions itself as a hub for modern business services (Goal 3), expecting the university to profile its graduates to meet the specific needs of the service sector and regional integration (Direction 3.1).

4. Siedlce – The Formalized Partnership Model

Siedlce with 75,072 residents (Polska w liczbach, 2025) is a hub in the Masovian Voivodeship aspiring to the role of a subregional center for education and culture. Strategic analysis (Urząd Miasta Siedlce, 2015) indicates that the city builds its advantage through formalized cooperation structures.

Location (L): The analysis points to a development model based on strengthening central and academic functions (Goal 2.2) and improving quality of life through housing (Goal 4.3), which offers students stability and predictability in a BANI world.

Technology (T): The focus is on ICT infrastructure development, including increasing bandwidth and implementing e-services (Goal 4.5), providing the technical foundation for a modern economy.

Relations (R): A distinguishing feature is the support for lifelong and practical learning and the promotion of the city's academic brand. The strategy emphasizes the formalized integration of educational activities with the potential of universities, including support for academic cultural ventures, which serves as a way to mitigate the incomprehensibility (I) of procedures and the environment.

The Siedlce model is conservative yet resilient—it assumes the evolutionary development of academic functions as an integral, internal part of the urban socio-economic ecosystem.

4.2. Development Strategies of Public Higher Education Institutions in Non-Metropolitan Cities – A Case Study

A comparative analysis of the development strategies of the studied institutions, cross-referenced with data on their market positioning, enables the empirical verification of the LTR framework's assumptions.

4.2.1. Strategic Baseline: Rankings and Graduate Labor Market Outcomes

The comparison of ranking positions (Table 2) confirms the hypothesis of a 'low initial standing' for the institutions under study. In global rankings, such as Webometrics, institutions with established brands (Siedlce, Słupsk) occupy lower-tier positions (exceeding 8000), whereas recently transformed entities (Piotrków, Kalisz) exhibit limited visibility or are entirely absent from specific databases (e.g., EduRank). This can largely be attributed to their relatively short period of operation under new legal frameworks, which delays comprehensive indexing by ranking algorithms. Furthermore, the scale of their operations (900 – 5245 students) deviates significantly from the selected analytical counterpoints, such as the University of Warsaw (approx. 35,000 students) and the University of Cambridge (approx. 25,000 students). This disparity necessitates the pursuit of competitive advantage through factors other than economies of scale

Table 2.

Ranking performance of the analyzed higher education institutions in EduRank 2025 and Webometrics 2025

University	EduRank 2025	Webometrics 2025	Total students
University of Cambridge	2 (Europe) 2 (UK)	10 (World) 2 (Europe) 2 (UK)	24 912
University of Warsaw	93 (Europe) 1 (Poland)	368 (World) 140 (Europe) 1 (Poland)	35 425
Piotrków Academy	Not indexed*	Not indexed*	900
Kalisz University	Not indexed	11 747 (World) 275 (Poland)	4000

Cont. table 2.

Pomeranian University in Słupsk	1835 (Europe) 80 (Poland)	9382 (World) 2007 (Europe) 98 (Poland)	3000
University of Siedlce	1043 (Europe) 62 (Poland)	8405 (World) 1849 (Europe) 91 (Poland)	5245

* The lack of data may be attributable to the brief duration of the institution's operation under its current nomenclature and legal status (following its succession from the UJK Branch), which precludes comprehensive algorithmic indexing.

Source: own study based on the EduRank, 2025, Webometrics, 2025, University of Cambridge. Information Hub (as of 01.12.2024), Uniwersytet Warszawski. *Dane statystyczne – Studenci*, 2024 (as of 31.12.2024), Gosławska, 2024, Latarnik Kaliski, 2024.

Analysis of data from the Polish Graduate Tracking System (ELA, 2023), presented in Figure 3, provides insights into the functioning of the studied institutions within their local ecosystems (Dimension R).

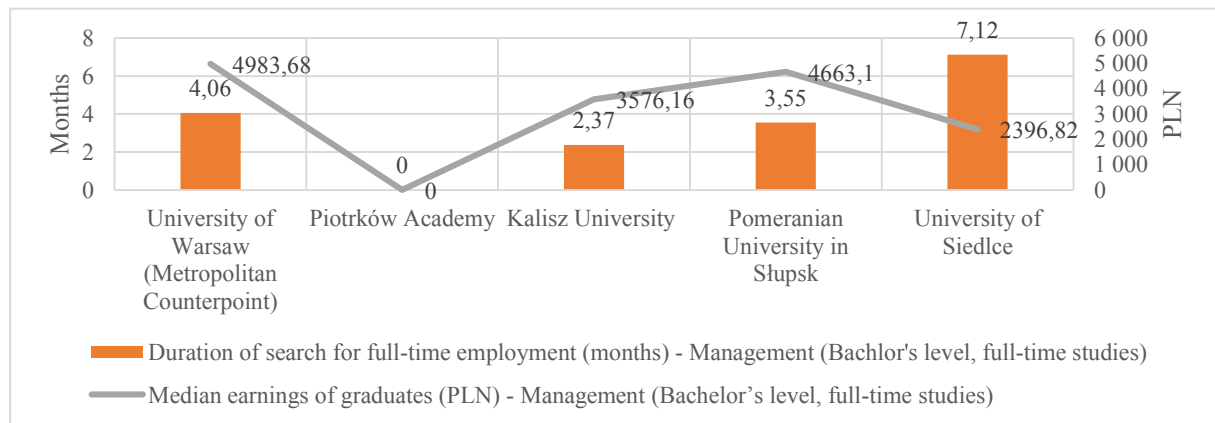


Figure 3. Recruitment data and graduate labor market outcomes (median earnings and job search duration) for the analyzed institutions.

Source: own study based on the Ogólnopolski System Monitorowania Ekonomicznych Losów Absolwentów Szkół Wyższych (ELA, 2023).

Data from the Polish Graduate Tracking System (ELA, 2023) are used in an illustrative and contextual manner and do not constitute a basis for causal inference. Their role is to complement the qualitative findings by providing descriptive insight into graduate outcomes within local labor markets.

The salary landscape highlights the distinct specificities of non-metropolitan markets. The median earnings of graduates from the studied institutions, ranging from 2,396.82 PLN to 4,663.1 PLN, are nominally lower than the average for metropolitan hubs such as Warsaw (4,983.68 PLN). However, when interpreting this data through the lens of Dimension L (Locational) and the relatively lower cost of living in Siedlce, Słupsk, or Kalisz, the real purchasing power of graduates remains at a satisfactory level, which encourages regional retention.

In BANI conditions, the key indicator of success proves to be employment stability and the speed of entry into the workforce, rather than the salary amount alone. As shown in the chart, the duration of the first full-time job search is relatively short, averaging less than 2.5 months (Kalisz University graduates) and approximately 3.5 months (Pomeranian University in Słupsk graduates). This suggests high local market absorption capacity and an effective alignment of the educational offering with the needs of regional employers.

Low unemployment rates among graduates and short job search durations confirm that the studied universities serve as local economic stabilizers. In contrast to metropolises, where the "rat race" for positions generates high levels of Anxiety (A), graduates of non-metropolitan institutions benefit from a relation premium (Dimension R), quickly finding employment through local business and institutional networks.

A notable exception is found among graduates of the University of Siedlce (UwS), whose full-time job search exceeds 7 months, with median earnings being the lowest among the institutions studied. This phenomenon can be tentatively linked to the specific configuration of the L and R dimensions. Unlike other regional centers with similar student populations, such as Kalisz or Słupsk, where the job search duration is significantly shorter (approx. 2.5 and 3.5 months, respectively), the situation in Siedlce may potentially reflect a periodic saturation of the local labor market. Furthermore, it can be hypothesized that the unique economic gravity of Warsaw induces a 'selective search' effect; graduates from UwS may prioritize longer-term aspirations for the metropolitan market over immediate local employment. Thus, these results may reflect ambitious career strategies rather than institutional inefficiency, although this interpretation would require further verification.

4.2.2. University Development Strategies Through the LTR Lens

A detailed analysis of strategic documents reveals diverse models of adaptation to BANI conditions. It should be emphasized that while these strategies are multifaceted and extend beyond the scope of this study, the application of the LTR conceptual model as an original analytical tool allowed for the identification and extraction of those priorities that determine the building of competitive advantage in non-metropolitan centers.

Under this research filter, the content analysis process enabled the mapping of fragmented strategic provisions onto specific components of the model:

In the area of Location (L): Identified goals concern the modernization and expansion of physical infrastructure, building spatial autonomy (particularly important for new entities), and improving the quality of life and architectural accessibility of the campus.

In the area of Technology (T): Selected provisions cover the digitization of management and administrative processes, the implementation of modern didactic tools, and the construction of specialized R&D centers serving as a technological base for the region.

In the area of Relations (R): Extracted mechanisms include institutional cooperation with businesses and clusters, formalized collaboration with local governments, and the fulfillment of the university's "Third Mission" as a cultural hub.

This research procedure does not imply that the LTR framework exhausts the entire content of the studied documents; rather, it serves as a high-precision tool for distilling the key determinants of institutional resilience.

The following results present the operationalization of the LTR analytical framework using specific examples from the studied institutions.

1. Piotrków Academy – Priority: Infrastructural Autonomy

The analysis of the *Development Strategy for 2024-2028* (Akademia Piotrkowska, 2025) indicates a concentration of efforts on building subjectivity after years of operating as a branch.

Location (L): This dimension is defined as a physical struggle for the institution's own space. Under Priority 5 ("Structure"), the document explicitly points to the need to mitigate "decades of neglect" and "imprudent management of the former branch's assets". The thorough modernization of buildings has thus become a key operational goal, forming the foundation of the university's new identity and ensuring its physical autonomy.

Technology (T): Treated instrumentally as a support for pedagogy (Priority 2: "Education"). The strategy assumes intensive improvement of distance learning methods to enhance the attractiveness of the lifelong learning offer and reach students beyond the traditional recruitment area.

Relations (R): Identified in the document as a *conditio sine qua non* for development. In Priority 4 ("Cooperation with the Environment"), the university declares its commitment to increasing the city's competitiveness, while Priority 3 ("Entrepreneurship") assumes the commercialization of research through special purpose vehicles (SPVs) to achieve financial independence and market integration.

2. Kalisz University – Model: Cluster Integration

The university's strategy (Uniwersytet Kaliski..., 2021) stands out for its strong profiling toward specific economic sectors of Southern Greater Poland.

Location (L): Built on two levels: improving living conditions (modernizing dormitories under the goal "Increasing the Attractiveness of Housing Offer") and branding activities. The planned relocation of the university authorities to the prestigious National Bank of Poland (NBP) building aims to symbolically and functionally anchor the university in the city's elite center.

Technology (T): Forms the foundation of research specialization. The development of the Monoprofile Medical Simulation Center and the R&D Center is not merely an equipment investment but a strategic positioning of the university as an advanced technological back-end for the region.

Relations (R): This is the most strongly outlined dimension. The university institutionalizes cooperation through targeted "participation in economic clusters", explicitly mentioning the aviation and food clusters. Thus, the university acts as an R&D department for the Kalisz-Ostrów Agglomeration. This is complemented by social initiatives (Children's University, University of the Third Age) building intergenerational bonds.

3. Pomeranian University in Słupsk – Strategy: Digital Transformation

The mission and strategy (Academia Pomorska w Słupsku, 2021) emphasize modern management, reflecting its recently attained university status.

Location (L): Focus on territorial expansion—the strategy assumes the creation of a Field Research and Teaching Station, physically extending the center's reach. Simultaneously, efforts are made to build the brand as a strong, autonomous center in Central Pomerania.

Technology (T): The dominant dimension in management. Strategic documents detail the implementation of Electronic Document Management (EZD) systems and IT tools for financial control. In research, technology supports the digitization of the region's natural resources (the *Herbarium Pomeranicum* project), serving as a unique research differentiator.

Relations (R): Based on formalized advisory structures. A key mechanism is the establishment of Employers' Councils at the institutes, ensuring market verification of curricula. Another vital element is the "Third Mission", positioning the university as the city's primary cultural center.

4. University of Siedlce – Model: The Accessible University

The strategy through 2025 (Uniwersytet w Siedlcach, 2019) strongly emphasizes inclusivity, stability, and social responsibility.

Location (L): The priority is "universal design" and ensuring full architectural accessibility for people with special needs. The internal dimension of location is reinforced by employee wellbeing—the strategic goal "The University as a Friendly and Secure Employer" aims to build staff stability in an uncertain environment.

Technology (T): Understood pragmatically as streamlining financial and administrative systems and developing library infrastructure (Main Library and Scientific Publishing House), providing a workshop base for researchers and students.

Relations (R): Oriented toward the labor market (strategic goal "High Quality of Education") and tracking graduate outcomes. The strategy also assumes the intensification of international research cooperation, complementing strong traditional ties with local government and business.

5. Discussion

The strategic review and market position analysis of the examined institutions enable the formulation of generalized conclusions regarding the mechanisms for building competitive advantage. The subsequent discussion interprets these findings through the lens of the LTR conceptual model components, the BANI framework, and the existing literature. To bridge the gap between specific case study observations and generalized conclusions, Table 3 provides

a synthesis of the identified strategic archetypes, which serve as the foundation for the following analysis.

Table 3.

Synthesis of Strategic Priorities: The LTR Framework Perspective

Institution	Dominant Dimension	Strategic Profile (Archetype)	Key Actions (Documentary Evidence)
Piotrków Academy	L (Location)	Restoration of Autonomy	The priority is to regain institutional agency after operating as a branch. Emphasis is placed on "building modernization" (Priority 5) and developing internal infrastructure to ensure independence from the central headquarters.
Kalisz University	R (Relations)	Industrial Integration	The strategy is strictly aligned with economic clusters (aviation, food). Goal: "Participation in cluster activities", which positions the university as an R&D hub for regional industry.
Pomeranian University in Słupsk	T (Technology)	Systemic Digitization	Strong emphasis on e-management (EZD – electronic document management, financial control – Objective 1.3). Technology is treated as a tool for streamlining processes and enhancing organizational efficiency.
University of Siedlce	L and R (Location and Relations)	Inclusivity and Openness	"Accessible University" strategy (universal design). Goal: "The university as a friendly employer". Building competitive advantage through wellbeing and staff stability. Strategic Goal "Cooperation with the Environment"

Source: own study based on the strategic documents of analyzed universities.

The analysis confirms that under BANI conditions, the studied institutions do not replicate metropolitan models. Their strategic actions, interpreted through the lens of the LTR framework, demonstrate high alignment with its dimensions and focus on institution-specific deficits or assets (Table 3). For emerging centers (Piotrków), the priority is the physical infrastructure and autonomy (L); for those with technological aspirations (Słupsk), it is the digitization of management processes (T); and for those deeply integrated with industry (Kalisz), it is cluster networking (R). Conversely, for institutions with a social profile (Siedlce), inclusivity and fostering environmental stability (Land R) become paramount. Applying the LTR framework as an interpretive tool leads to the conclusion that the common denominator for all studied entities is the treatment of relationality as a key driver of institutional resilience.

The subsequent discussion interprets these findings through the lens of the LTR conceptual model components, the BANI framework, and the existing literature.

5.1. The Significance of Location (L): Redefining Competitive Advantage Through Quality of Life and Study

The analysis confirms the fundamental role of location, as classically identified by M. Porter (1990, 2000); however, in the specific context of non-metropolitan cities, this factor takes on a new meaning. Research results suggest that, in accordance with O. Kethüda's typology (2021), the competitive advantage of smaller centers is no longer determined solely by 'hard'

geographical parameters, but rather by 'soft' assets: place attractiveness, safety, and quality of life.

For the studied institutions, this translates into a strategic focus on "Quality of Study" as a locational advantage. As evidenced by the "Restoration of Autonomy" archetype at Piotrków Academy and "Accessible University" at University of Siedlce (Table 3), Location (L) may lead to creation of sense of belonging, academic stability and well-being both students and academic staff. These observations align with the findings of Livina and Rozentale (2020), which indicate that in an era of uncertainty (BANI), well-being becomes a crucial strategic resource determining the decisions of students and talent alike.

It should be noted that this trend has significantly intensified in the post-pandemic era. The widespread adoption of hybrid work models and the rising popularity of the 'slow city' and work-life balance concepts have radically increased the attractiveness of non-metropolitan centers. These hubs offer a high quality of life at a relatively lower cost of living, providing a tangible argument in the competition for human capital.

Comparing the positions of the studied cities—such as Kalisz, Słupsk, or Siedlce—in quality-of-life rankings (Ranking miast powiatowych według poszczególnych kategorii, 2018) with their academic potential leads to the conclusion that a 'low start' in national rankings need not be a barrier; rather, it serves as a point of departure for strategic redefinition. Unlike metropolises, with their 'rat race', the analyzed cities can build an advantage based on social well-being indicators (Statistics Poland, 2024). In the LTR framework, this serves as a response to the Anxiety (A) and Brittleness (B) of the environment.

A further significant conclusion from the analysis concerns the role of the local labor market. In contrast to saturated metropolitan markets, smaller centers offer greater stability and lower competitive pressure (Business Insider, 2025). For regional universities, this presents an opportunity to build more durable relationships with employers, confirming the thesis that local attractiveness within the L (Location) dimension must be actively cultivated.

5.2. The Technological Dimension (T) as a Tool for Organizational Resilience

In the context of the BANI environment, the findings suggest that digital transformation in smaller centers is ceasing to be merely a technical challenge and is becoming a key tool for building organizational resilience (Mohamed Hashim et al., 2022). Although the level of digitization within the institutional environment of smaller cities varies (Miazga et al., 2022), the organizational agility of smaller universities allows them to adapt hybrid solutions more rapidly than is the case in complex metropolitan structures. The "Systemic Digitization" archetype identified at the Pomeranian University in Słupsk (Table 3) illustrates that technology (T) is not just an administrative add-on, but a way to mitigate geographic peripherality. It should be noted, however, that this potential agility of smaller units is not a permanent trait; rather, it depends on a proactive management stance and budgetary flexibility. In this context,

technology (T) emerges as a strategic opportunity, the full realization of which requires overcoming internal cultural barriers within the organization.

The necessity of addressing the needs of 'digital natives' (McHaney, 2011; Budde-Sung, 2011) compels the studied institutions to implement personalization and immediacy within their educational processes. Analysis indicates that virtualization (MOOCs, open access) serves as a strategic equalizer for non-metropolitan universities, effectively mitigating geographic barriers. Furthermore, the utilization of technologies such as Big Data and Cloud Computing in institutional management (Mazurek, 2019) allows for more effective prediction and error elimination. In light of the LTR framework, the technological dimension (T) not only supports pedagogy but also constitutes a direct response to the non-linearity (N) of the environment.

5.3. University-City Relations (R): Moving Beyond the Triple Helix Model

Analysis of the development strategies of the studied cities indicates that university-environment relations are evolving. The observed actions—comparable to initiatives in leading hubs (e.g. Urząd Miejski Wrocławia, 2025), as well as specific strategies of the analyzed centers (Siedlce, Słupsk)—demonstrate that contemporary innovation ecosystems are increasingly integrating civil society (Quadruple Helix) and the environmental perspective (Quintuple Helix) (Carayannis, Campbell, 2010).

Practical reflections of this multi-level integration are exemplified by the "Industrial Integration" archetype identified at Kalisz University, the "Openness" archetype of University of Siedlce (by among others "Cooperation with the Environment") (Table 3) or Herbarium Pomeranicum project conducted by Pomeranian University in Słupsk. It combines the advanced digitization of natural resources (T) with broad knowledge dissemination to the public (R), thereby achieving scientific, educational, and environmental goals within a single ecosystem.

These findings correspond with the City Academic Index (PIE, 2023), confirming a bidirectional relationship: a strong university stimulates demographics and the labor market, while a developed city attracts academic talent (Dębkowska et al., 2023; Kozień, 2021). In the case of non-metropolitan cities, this symbiosis is particularly evident—the university serves as an anchor institution, and its collaboration with business is a prerequisite for curbing brain drain.

The anchor institution role should not be idealized, as its effectiveness remains contingent upon regional absorptive capacity, institutional resources, and the quality of inter-organizational coordination.

These partnerships, by enhancing institutional image and ranking positions (Bogacz-Wojtanowska et al., 2022), grant universities access to external resources, which underscores the efficacy of the LTR analytical framework in smaller academic centers.

5.4. International Context: Evidence Verifying the Analytical Framework

The significant impact of universities on the development of non-metropolitan cities is a globally observed phenomenon, confirming the universality of the conclusions derived from the LTR analytical framework. International case studies demonstrate that metropolitan status is not a prerequisite for success:

Cambridge (Massachusetts, USA): A city with a population of approximately 118,000 (NCES: medium city), where the presence of Harvard and MIT has fostered a powerful innovation ecosystem (City of Cambridge MA, 2025; MIT, 2023).

Cambridge (United Kingdom): A center with approximately 152,000 inhabitants (ONS: large towns/smaller cities), serving as the core of the "Silicon Fen" cluster (Cambridge City Council, 2025).

Stanford (California, USA): A small census-designated place (approx. 21,000 residents) whose global influence stems from the synergy between the Stanford University and the City of Palo Alto (City of Palo Alto, 2025).

These examples demonstrate that the factors determining a university's global standing are independent of urban scale. For the "digital native" generation, the physical scale of an academic center is becoming secondary to digital utility (T) and the quality of engagement with the market (R), rather than a metropolitan address (L).

The conducted analysis of strategic documents reveals fundamental differences in the development priorities of the studied institutions, as summarized in Table 4. It should be emphasized that the University of Cambridge was included in this analysis not as a direct competitor for the studied units, but as a theoretical aspirational model (proof of concept), demonstrating that a non-metropolitan location does not constitute an insurmountable barrier to achieving global academic success.

Table 4.

Comparative analysis of LTR analytical framework components for non-metropolitan universities and counterpoint institutions

Dimension	Regional Universities	University of Warsaw	University of Cambridge
Location (L)	Regional Support: Counteracting depopulation, improving the quality of life for residents.	Environment: High-quality work and study environment, well-being, metropolitan impact.	Social Impact: Social equality, sustainable development, social justice, global social impact.
Technology (T)	Efficiency: Infrastructure modernization, e-services, improving remote learning conditions.	Transformation: Hybrid education models, cybersecurity, workplace flexibility.	Innovation: Technology-driven research, global projects, and commercialization of results.
Relations (R)	Operational Necessity: Local government cooperation, labor market alignment, strengthening the city's academic profile.	Leadership: Partnerships for innovation and regional leadership; challenge: limited business integration.	Ecosystem: Ecosystem-wide collaboration, research commercialization, global partnerships with business and foundations.

Source: own study based on the strategic documents of analyzed universities.

Interpreting the data (Table 4) through the lens of the formula Competitive Advantage = $L \cdot T \cdot R$ (1), the following discussion points can be formulated:

Regional universities build their positioning upon a strong foundation in the L and R dimensions. Their advantage is essentially stabilizing; they are indispensable for the survival of the urban centers in which they operate. The T dimension remains a challenge, currently serving an instrumental function (addressing infrastructural deficits). To progress, it must evolve into a driver of unique quality and organizational agility.

The University of Warsaw possesses significant potential in the L and T dimensions. However, compared to the global analytical counterpoint, the R dimension—specifically regarding commercialization—remains a challenge. For the advantage to become truly multiplicative (synergistic), it is necessary to deepen substantive business cooperation that extends beyond mere formal partnerships.

The University of Cambridge achieves maximum saturation across all three variables. The synergy between T (technology) and R (business ecosystem), situated within a favorable L environment (the high quality of life of a mid-sized city), generates a global competitive advantage.

This confirms that the LTR framework is a robust tool for navigating the 'brittleness' of the modern educational landscape. The synergy of these dimensions allows non-metropolitan centers to transition from defensive-adaptive strategies (aimed at survival) toward a proactive niche-building path by linking a unique location (L) with specialized technology (T) and supra-local relational networks (R).

6. Summary

The objective of this article was to identify the sources of competitive advantage for public academic universities located in non-metropolitan cities under conditions of uncertainty conceptualized by the BANI framework. The analysis of four case studies (Piotrków Academy, Kalisz University, Pomeranian University in Słupsk, University of Siedlce) and the non-metropolitan cities in which they operate, supported by a review of strategic documents, confirmed the utility of the author's original LTR (Location, Technology, Relations) conceptual model as an interpretive framework for the development of smaller academic centers.

The primary conclusions of the study can be summarized as follows:

Location (L) as a resource rather than a barrier. The analysis shows that in a BANI world, "peripherality" loses its pejorative connotation. By offering a higher quality of life, safety, and lower living costs, smaller centers may become an attractive alternative to overcrowded metropolises. In this context, location functions as a stabilizing factor that mitigates anxiety and competitive pressure. When combined with appropriately designed resource policies,

this translates into favorable graduate career outcomes and a high quality of study (quality of life/study synergy).

Technology (T) as a strategic equalizer. The organizational agility of the analyzed universities enables the effective adaptation of digital solutions that mitigate geographical distance. Unlike global analytical counterpoints, where technology often serves an "innovation race", in Polish non-metropolitan cities it primarily fulfills an inclusive and integrative function. The digitization of processes becomes a tool for the democratization of knowledge, compensating for infrastructural deficits in the surrounding environment.

Relations (R) as the foundation of institutional existence. The findings indicate that the analyzed universities function as critical "anchor institutions". Their development strategies are inextricably linked with the strategies of the cities in which they operate, reflecting close cooperation among academia, business, and local government. Without deep, multi-dimensional relationships with their environment, these universities lose their reason for existence, as they lack the critical mass required to function as autonomous entities.

In light of the LTR analytical framework, the competitive advantage of non-metropolitan universities does not stem from economies of scale, but from a unique synergy of close relations and technology within a more stable environment, expressed by the formula Competitive Advantage = $L \cdot T \cdot R$ (1). This multiplicative relationship suggests that the absence or failure of any single dimension significantly diminishes the overall strategic potential. Therefore, a high quality of life (L) alone is insufficient without the digital tools (T) to overcome peripherality and the relational networks (R) to anchor the institution within the regional economy. Consequently, attempts to mechanically replicate metropolitan strategies (e.g., those of the University of Warsaw) cannot yield comparable outcomes under non-metropolitan conditions.

While these conclusions highlight the strategic potential of the LTR framework, the study is not without limitations, which should be taken into account when interpreting the findings.

The primary limitation of this study lies in its qualitative nature and its focus on the specificities of the Polish higher education system. Although the multiple case study approach allowed for an in-depth exploration of the LTR analytical framework's mechanisms, it does not permit full generalization of the findings to other cultural or legal contexts.

Furthermore, an analysis based on strategic documents is inherently declarative, reflecting the planning intentions of university and city authorities (intended strategy). In the dynamic conditions of the BANI environment, these may diverge from the actual degree of implementation (realized strategy).

In addition, data on graduate career outcomes (ELA, 2023) were used solely in a descriptive and contextual manner. Future research should therefore focus on quantitative verification (statistical analysis) aimed at testing the strength of the relationship between the synergy of the LTR dimensions and hard indicators of universities' economic and scientific performance. Despite these limitations, the study provides analytically transferable insights into the strategic logic of non-metropolitan universities operating under BANI conditions.

Beyond its analytical contribution, this study offers practical and societal relevance. The LTR framework provides a context-sensitive diagnostic tool and analytical perspective that may inform policymakers and university leaders, suggesting that the development of public universities in non-metropolitan cities should prioritize contextual specialization rather than the mechanical replication of metropolitan development models. At the same time, the findings underscore the role of public universities as anchor institutions that enhance regional resilience by counteracting brain drain and long-term territorial weakening under conditions of uncertainty.

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INTERGOVERNMENTAL DISPUTE AS A FACTOR DETERMINING CONSUMER BEHAVIOR IN THE CROSS-BORDER MARKET

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Purpose: This paper examines the impact of the Polish–Czech intergovernmental dispute over the Turów Brown Coal Mine on consumer activity and behavior in the cross-border market of the Nysa Euroregion, aiming to assess whether a political conflict at the central level translates into changes in everyday consumer behavior in a borderland context.

Design/methodology/approach: The study is based on quantitative research conducted in 2022 among 330 Polish and Czech residents of the Nysa Euroregion. Data were collected using a standardized questionnaire and analyzed using statistical techniques, including factor analysis and structural equation modeling (SEM).

Findings: The results indicate that the intergovernmental dispute had a statistically significant negative impact on cross-border consumer activity. The effect was stronger among Czech consumers than Polish ones; however, in both cases it was relatively weak and temporary, not leading to lasting changes in consumer behavior.

Practical and social implications: The findings suggest that intergovernmental disputes can temporarily disrupt cross-border markets by weakening trust, intensifying national divisions, and limiting everyday economic and social interactions in border regions.

Originality/value: The paper contributes to the literature by empirically demonstrating how a central-level intergovernmental dispute affects local consumer behavior in a cross-border market—an area that remains underexplored in existing research.

Keywords: intergovernmental dispute, cross-border market, Euroregion Nysa, consumer behavior.

Category of the paper: research paper.

1. Introduction

Before discussing the impact of the Polish-Czech dispute over the Turów Lignite Mine (KWB Turów) on consumer activity and behavior in the cross-border market of the Nysa Euroregion, it is necessary to define the very concept of an international dispute. Such a dispute is often defined as a disagreement or divergence of views regarding the actual interests of states and the ways of resolving them (Pawłowski, 2006). In other words, it is a kind of collision of

views concerning factual situations and international norms (Kragiel, 2017; Malendowski, 1996). Such a collision most often arises when one state claims to hold certain rights (e.g., the right to extend a concession for the extraction of a mine operating in the borderland), while another state denies these rights; when one state formulates claims that are rejected by the other; when one state demands certain conduct from another (e.g., the cessation of mining operations), and the latter rejects such demands; or when the actions of a given state violate the rights or interests of another state (Czarnocki, Pietraś, 1988). A dispute thus means that in relations between states (e.g., between Poland and the Czech Republic), specific claims are made by one subject of international law against another. It usually concerns divergences regarding the assessment of legal and political norms, as well as factual circumstances (Cała-Wacinkiewicz, 2011).

An analysis of the literature shows that international disputes arise from the existence of conflicting particular interests of individual states of political, economic, or ideological nature, and most often concern issues such as (Kragiel, 2017):

- violation of state security, including problems related to border traffic and migration control (e.g., the migration issue on the Polish-Belarusian border),
- interference in the internal or foreign policy of a sovereign state, or its political system,
- the delineation of state borders (e.g., the Indian-Pakistani conflict over Kashmir),
- or, as in the case under discussion, the extraction of natural resources.

It should also be remembered that any intergovernmental dispute may stem from one or several of these causes simultaneously, and their escalation often depends on domestic politics, the international balance of power, or current events.

The Polish-Czech intergovernmental dispute over KWB Turów arose in connection with the mining activities of the mine near the Czech-Polish-German border (the Polish part of the Nysa Euroregion). The Czech side, particularly the residents and authorities of the Liberec Region (Cz. Liberecký kraj), expressed concerns that the continued exploitation of the Polish mine was lowering groundwater levels, causing noise and pollution, and negatively affecting the environment and the lives of residents on the Czech side of the border. In 2020, the Czech Republic officially opposed the extension of the lignite mining concession in Turów until 2026. In 2021, it filed a complaint with the Court of Justice of the European Union (CJEU), demanding the suspension of mining operations. As a result, the CJEU upheld the complaint, obliging Poland to immediately cease mining activity. The Polish government, contrary to the decision, decided to continue extraction, which resulted in a record financial penalty of 500,000 euros per day. Despite efforts (mainly by the Polish side), the dispute ended only in February 2022 with the signing of an intergovernmental agreement. Poland committed itself to undertaking compensatory measures, including paying the Czech Republic 45 million euros in compensation (Wróblewski, 2024).

The dispute over KWB Turów was a consequence of unilateral pursuits and viewing one's own interests without regard for the different arguments or interests of the neighbor. Consequently, the realization of particular national interests led to antagonisms and mutual resentment among citizens of both countries. Extensive, often biased commentary on the dispute in national, regional, and local press as well as on social media also translated into situations or disputes at the local level. Analyses by the Institute of Media Monitoring (IMM) indicate that the topic of the Polish-Czech dispute over KWB Turów, between September 2020 and September 2021, was covered nearly 120,000 times by journalists across all types of media in Poland and the Czech Republic, including over 75,000 mentions on social media, where it was discussed by politicians, experts, citizens, and pro-environmental organizations. According to IMM estimates, every Polish citizen over the age of 15 could have encountered information about KWB Turów an average of 72 times in television, radio, press, and online portals, and at least once on social media. In the Czech Republic, these figures were 58 times in traditional media and 6 times on social channels ("The Polish-Czech dispute over Turów").

This raises the question of whether such a widely publicized Polish-Czech intergovernmental dispute translated into changes in consumer behavior in the Polish-Czech cross-border market, particularly in the Nysa Euroregion, where the subject of the dispute – KWB Turów – is located. For the purposes of this study, the Polish-Czech cross-border market is defined as a set of buyers (consumers) and sellers conducting transactions in areas along the Polish-Czech border, on both the Polish and Czech sides. The functioning of this market results from spatial proximity, socio-economic ties, and the institutional framework of cross-border cooperation within the European Union (cf. Wróblewski, 2018, 2019, 2020). The geographical understanding of a cross-border market refers to a territory situated on both sides of the border as a distinct area with similar conditions for making purchases and sales. With regard to the Polish-Czech cross-border market of the Nysa Euroregion, this refers to the territory of the Nysa Euroregion. The classical (economic) understanding of the market reduces the definition of a cross-border market to the totality of exchange relations between sellers offering products (including services) that satisfy needs, and buyers – representing the demand for them.

Despite the growing body of literature on international disputes, consumer ethnocentrism, and cross-border cooperation, empirical studies directly linking intergovernmental conflicts to everyday consumer behavior in cross-border markets remain scarce. Existing research has primarily focused on large-scale trade relations, national-level boycotts, or historical animosities, while relatively little attention has been paid to local border regions where political disputes intersect with routine economic and social interactions. This study addresses this gap by examining how a contemporary intergovernmental dispute concerning the Turów lignite mine—translates into changes in consumer activity in a specific European borderland. By combining survey data from both sides of the Polish–Czech border with structural equation modeling, the paper offers original empirical evidence on the mechanisms through which

political tensions at the central level affect consumer behavior at the local, cross-border market level.

In order to answer the research questions, a Polish-Czech research team conducted a study in 2022 within the project entitled “The Turów Mine Crisis and Its Impact on Czech-Polish Cross-Border Cooperation: Assessment, Conclusions, and Recommendations”. The project was funded by the National Agency for Academic Exchange, based in Warsaw. This article presents selected results of the research conducted.

2. Methods

For the purposes of the conducted research, it was assumed that the dispute concerning KWB Turów (at the central level – between the governments of Poland and the Czech Republic) exerted a significant negative impact on the activity of Polish and Czech consumers in the cross-border market of the Nysa Euroregion. Two research hypotheses were adopted:

- H1: The PL–CZ intergovernmental dispute over KWB Turów had a discouraging effect on the activity of Czech consumers on the Polish side of the cross-border market in the Nysa Euroregion.
- H2: The PL–CZ intergovernmental dispute over KWB Turów had a discouraging effect on the activity of Polish consumers on the Czech side of the cross-border market in the Nysa Euroregion.

To verify the formulated hypotheses, a survey was conducted in 2022 among 330 consumers – residents of both the Polish and Czech sides of the Nysa Euroregion (the Polish side of the Nysa Euroregion is inhabited by approximately 600,000 people, while the Czech side by about 500,000 – a total of 1,100,000). The appropriate sample size (representative of the entire population of the Nysa Euroregion) was calculated using a sample size calculator, assuming a maximum error of 5% and a confidence level of 95%. Due to the lack of a sampling frame, the survey included consumers residing on both the Polish and Czech sides of the Nysa Euroregion. These were also individuals who were familiar with the dispute over KWB Turów. Considerable effort was made to ensure that the research sample, in terms of such characteristics as gender, age, and education, was as accurate a reflection as possible of the entire population affected by the Turów issue. The study was carried out in the municipality of Bogatynia, and on the Czech side it covered residents of the towns of Hrádek nad Nisou, Chrastava, Heřmanice, Kunratice, and Višňová.

Data were collected using a standardized paper questionnaire. A total of 400 consumers participated in the survey. After verification, incomplete or erroneous questionnaires were discarded, which resulted in 330 correctly completed questionnaires (194 filled in by consumers on the Polish side and 136 by consumers on the Czech side). Women accounted for 58.18% of

the sample, men for 41.82%. The largest group of respondents (27.69%) were aged 45-54, followed by those aged 55-64 (18.46%). The clear majority of respondents had secondary education (54.29%), while 22.09% were individuals with vocational education (see Table 1).

Table 1.
Respondents' personal data

	Metric data	Percentage
Gender	Woman	58,18
	Man	41,82
Age	From 18 to 24 years old	13,85
	From 25 to 34 years old	10,46
	From 35 to 44 years old	16,62
	From 45 to 54 years old	27,69
	From 55 to 64 years old	18,46
	Over 64 years old	12,92
Education	Basic	3,68
	Vocational	22,09
	Secondary	54,29
	Higher	19,94

Source: own research.

The frequency and main reasons for crossing the Polish-Czech border by surveyed consumers – residents of the Nysa Euroregion, with an indication of the purpose of crossing the border – are presented in Table 2.

Table 2.
Main reasons for crossing the Polish-Czech border by surveyed residents of the Nysa Euroregion (% of respondents)

Specification	very often ****		often ***		rarely **		very rarely *		I am not crossing the Polish-Czech border for the stated purpose	
	PL	CZ	PL	CZ	PL	CZ	PL	CZ	PL	CZ
Family/Friends	3,80	0	10,87	7,63	11,41	7,63	7,62	5,93	66,30	78,81
Work	7,07	0	1,09	3,51	1,09	9,65	1,63	3,51	89,13	83,33
Business	1,10	0,88	1,10	5,32	2,20	0,88	6,04	7,08	89,56	85,84
Shopping	1,10	3,28	6,52	24,59	16,30	28,69	26,63	27,05	49,45	16,39
Educational offer	0	0	2,18	1,73	2,73	5,17	1,64	12,93	93,45	80,17
Medical services	0	0	1,10	0	3,82	0,89	8,20	6,25	86,88	92,86
Culture/Entertainment	3,25	0,90	8,70	1,80	11,95	9,01	25,00	27,03	51,10	61,26
Sports/Tourism	8,64	0	15,14	7,02	20,54	21,93	25,95	31,58	29,73	39,47
Travel (transit)	10,5	8,62	14,29	8,62	26,45	19,83	22,75	26,72	25,93	36,21

**** at least three times a week, *** about once or twice a week, but no more than three times a week, ** at least once a month, but no more than three times a month, * about once or twice a year, but no more than once a month.

Source: own research.

The most common reason for crossing the Polish-Czech border among Czech respondents was shopping – nearly 28% of those surveyed used this opportunity very often or often, followed by travel (transit journeys). Polish respondents most frequently crossed the border in connection with international travel (transit) and for tourism-related purposes (sports/tourism).

When determining the impact of the Polish-Czech intergovernmental dispute on the activity of Czech and Polish consumers in the cross-border market of the Nysa Euroregion, it was necessary to define the components of the dimension relating to the Polish-Czech intergovernmental dispute over KWB Turów. These components, formulated as appropriately designed statements, were intended for use in surveys of Polish and Czech consumers. The statements were defined on the basis of information obtained from experts (representatives of the Nysa Euroregion and local government officials involved in cross-border cooperation) during earlier qualitative research (IDI, FGI). As a result, five statements were developed to measure the significance of the Polish-Czech intergovernmental dispute over KWB Turów for consumer activity in the cross-border market of the Nysa Euroregion. The surveyed consumers were asked to indicate the extent to which they agreed with the following statements:

- Q1.1. The dispute over the Turów Mine weakened ties between Poles and Czechs.
- Q1.2. The dispute over the Turów Mine made me stop perceiving the area on the other side of the border as a place I would like to visit.
- Q1.3. The dispute over the Turów Mine made me stop being interested in the problems of neighbors living on the other side of the border.
- Q1.4. The dispute over the Turów Mine made me lose faith in the purpose of further development of Polish-Czech relations.
- Q1.5. The dispute over the Turów Mine made me realize how much divides Poles and Czechs.

These statements were adjusted to a five-point Likert scale ranging from “strongly disagree” (-2) to “strongly agree” (2).

The tendency of surveyed consumers from the Polish and Czech sides of the Nysa Euroregion to engage in activity in the cross-border market was measured by means of six statements developed (similarly to the previous case) on the basis of interviews conducted with experts of the Nysa Euroregion’s cross-border market (six statements referring to consumers from the Czech side of the Nysa Euroregion and six to consumers from the Polish side). The surveyed consumers were asked to determine the impact of the intergovernmental dispute over KWB Turów on local cross-border activity in the following areas:

- Q2.1. Employment of Czechs in Poland / Employment of Poles in the Czech Republic.
- Q2.2. Shopping by Czechs in Poland / Shopping by Poles in the Czech Republic.
- Q2.3. Tourist trips of Czechs to Poland / Tourist trips of Poles to the Czech Republic.
- Q2.4. Cultural trips of Czechs to Poland / Cultural trips of Poles to the Czech Republic.
- Q2.5. Business contacts between Czechs and Poles / Business contacts between Poles and Czechs.
- Q2.6. Czech-Polish social contacts / Polish-Czech social contacts (e.g., between local governments, firefighters, sports clubs, associations, etc.).

All statements were adjusted to a five-point Likert scale ranging from “-2” (definitely negative impact) to “2” (definitely positive impact). The analyses applied a combination of exploratory and confirmatory statistics.

3. Results

3.1. The Impact of the Polish-Czech Intergovernmental Dispute over the Turów Lignite Mine on the Activity of Czech Consumers in the Cross-Border Market of the Nysa Euroregion

In order to estimate the impact of the dispute concerning the Turów lignite mine (at the central level – between the governments of Poland and the Czech Republic) on the activity of Polish and Czech consumers in the cross-border market of the Nysa Euroregion, the analysis first focused on data obtained from Czech consumers. The next step was to identify the factors (dependent and independent variables), which were then incorporated into the SEM model. The procedure began with a reliability analysis for the first question, which consisted of five test items. For this set of items, Cronbach’s alpha reached the value of 0.755. This result is satisfactory; however, further analysis showed that removing item 1.1 would lead to a significant increase in the Cronbach’s alpha value (Table 3).

Table 3.
Cronbach's alpha after removing items

Specification	Position Statistics				
	Scale average after removing items	Scale variance after item removal	Total position correlation	Squared multiple correlation	Cronbach's alpha after item removal
pyt_1.1	9,71	9,334	0,144	0,181	0,826
pyt_1.2	10,72	6,848	0,674	0,528	0,655
pyt_1.3	10,72	6,794	0,616	0,592	0,674
pyt_1.4	10,67	6,847	0,594	0,409	0,682
pyt_1.5	10,19	6,992	0,615	0,398	0,676

Source: own research.

The reliability analysis showed that all items of the summative scale are strongly correlated with it (except for item 1.1). Therefore, in the further analysis, all statements were used except for item 1.1. Ultimately, for the four statements, Cronbach’s alpha coefficient equals 0.826. After eliminating statement 1.1, the Kaiser-Meyer-Olkin (KMO) measure is 0.785, which is a satisfactory result (the expected threshold is above 0.700). Hence, a significant reduction of the redundancy of the input set of four statements can be expected. Bartlett’s test of sphericity verifies the hypothesis that the correlation matrix between the input variables is an identity matrix, which would mean that no hidden factors are present. The result for the analyzed set is 161.443 ($p\text{-value} < 0.001$), which indicates rejection of the null hypothesis. Therefore, it can be

concluded that the use of factor analysis is justified. Table 4 presents the total explained variance for the factor consisting of the four statements.

Table 4.

Total explained variance – four statements

Component	Initial eigenvalues			Sums of squared charges after extraction		
	Total	% variance	% cumulative	Total	% variance	% cumulative
1	2,631	65,779	65,779	2,631	65,779	65,779
2	0,577	14,436	80,215			
3	0,468	11,700	91,915			
4	0,323	8,085	100,000			

Method of isolating factors – principal components.

Source: own research.

Assuming that the analyzed four statements constitute a single factor, it was observed that this factor explains 65.779% of the variability of the input data set. Thus, the reduction of the four-dimensional set to a single latent factor results in the loss of 34.221% of information. Assuming that only those variables should be selected for which the factor loadings exceed the threshold of 0.5 (in absolute value), the final factor loadings matrix is presented in Table 5.

Table 5.

Factor loadings matrix – four statements

Component matrix ^a	
Specification	Component
	1
pyt_1.3	0,861
pyt_1.2	0,814
pyt_1.4	0,799
pyt_1.5	0,767

Method of isolating factors – principal components.

a. 1 – number of separated components.

Source: own research.

The information presented in Table 5 indicates that all four variables have high, positive factor loadings on the analyzed factor, which is a desirable outcome. They show a strong correlation with the created latent factor.

Subsequently, a reliability analysis was conducted for the component measuring the propensity of the surveyed Czech consumers to engage in activities on the cross-border market of the Nysa Euroregion on its Polish side. This analysis was carried out (similarly to the previous case) using SPSS software and the reliability analysis module. The reliability analysis was performed for six test items. For this set of questions, Cronbach's alpha coefficient equals 0.873. The result is satisfactory, and further analysis showed that removing any item would not result in a significant increase in Cronbach's alpha (Table 6).

Table 6.*Cronbach's alpha after item deletion*

Position Statistics					
Specification	Scale average after removing items	Scale variance after item removal	Total position correlation	Squared multiple correlation	Cronbach's alpha after item removal
pyt 2.1	15,62	8,291	0,603	0,378	0,863
pyt 2.2	15,60	7,902	0,610	0,412	0,864
pyt 2.3	15,50	7,752	0,777	0,677	0,835
pyt 2.4	15,53	7,537	0,775	0,671	0,834
pyt 2.5	15,69	8,216	0,624	0,411	0,860
pyt 2.6	15,38	7,649	0,678	0,500	0,852

Source: own research.

The reliability analysis showed that all items of the summative scale are strongly correlated with it (above 0.6). Therefore, all analyzed statements should be used in the factor analysis. For the six statements comprising the question, the Kaiser-Meyer-Olkin (KMO) measure of 0.860 indicates that it is appropriate to conduct factor analysis. Similarly, Bartlett's test of sphericity (322.892, p -value < 0.001) leads to the rejection of the null hypothesis that the correlation matrix between the statements is an identity matrix. Table 7 presents the percentage of explained variance.

Table 7.*Total explained variance*

Component	Initial eigenvalues			Sums of squared charges after extraction		
	Total	% variance	% cumulative	Total	% variance	% cumulative
1	3,705	61,758	61,758	3,705	61,758	61,758
2	0,678	11,307	73,065			
3	0,541	9,015	82,080			
4	0,487	8,124	90,204			
5	0,383	6,389	96,594			
6	0,204	3,406	100,000			

Method of isolating factors – principal components.

Source: own research.

Assuming that the six analyzed statements constitute a single factor, it was observed that this factor explains 61.758% of the variability of the input data set. Thus, the reduction of the six-dimensional set to a single latent factor results in a loss of 38.242% of information. Assuming that only those variables should be selected for which the factor loadings exceed the threshold of 0.5 (in absolute value), the final factor loadings matrix is presented in Table 8.

Table 8.*Factor loadings matrix*

Component matrix ^a	
Specification	Component 1
pyt 2.3	0,865
pyt 2.4	0,864
pyt 2.6	0,789
pyt 2.5	0,741

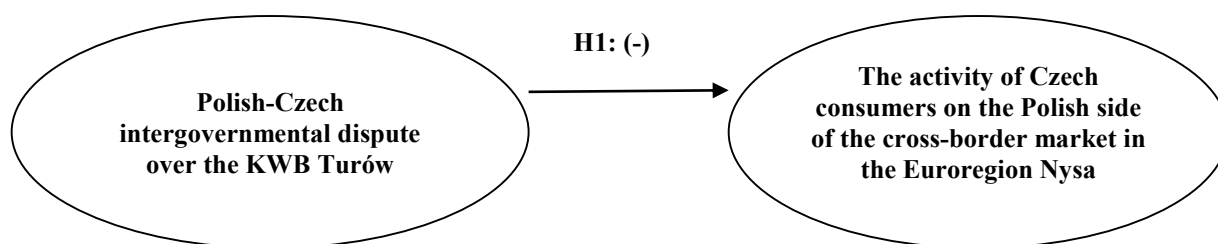
Cont. table 8.

pyt 2.2	0,727
pyt 2.1	0,715
Method of isolating factors – principal components.	
a. 1 – number of separated components.	

Source: own research.

The information presented in Table 8 indicates that all variables have high, positive factor loadings on the analyzed factor, which is a desirable result.

To estimate the impact of the Polish-Czech intergovernmental dispute over KWB Turów on the activity of Czech consumers on the Polish side of the cross-border market in the Nysa Euroregion, the latent variables were incorporated into a structural equation model (SEM – Structural Equation Modeling). The SEM analysis was conducted based on a factor model estimated using the principal components method, corresponding to the obtained results and the adopted assumptions (developed based on interviews with experts on the cross-border market of the Nysa Euroregion). The developed research model included the factors generated from the conducted analysis. In this model, a path structure was assumed to determine how the Polish-Czech intergovernmental dispute over KWB Turów influences the activity of Czech consumers on the Polish side of the cross-border market in the Nysa Euroregion – Figure 1.

**Figure 1.** Theoretical model – for Czech consumers of the Euroregion Nysa.

Source: own research.

The first hypothesis (H1) assumes that the intergovernmental dispute over KWB Turów exerted a dampening effect on the activity of Czech consumers on the Polish side of the cross-border market in the Nysa Euroregion. In other words, as Czech perceptions of Poles become increasingly negative (a reaction triggered by the PL-CZ governmental dispute), the willingness of Czech consumers to engage in activity on the Polish side of the cross-border market in the Nysa Euroregion decreases. The parameters of the estimated model are presented in Table 9.

Table 9.*Model coefficients – Czech consumers*

Specification			Model coefficient	Standardized coefficient	Standard error	t-statistic	p-value	R-squared
The activity of Czech consumers on the Polish side of the cross-border market in the Euroregion Nysa	<---	Polish-Czech intergovernmental dispute over the KWB Turów	-0,233	-0,360	0,080	-2,907	0,004*	0,129

* statistical significance at the level of 0.05.

Source: own research.

From the information presented in Table 9, it can be concluded that the PL-CZ intergovernmental dispute over KWB Turów has a negative (dampening) effect on the activity of Czech consumers on the Polish side of the cross-border market in the Nysa Euroregion. The relationship is statistically significant and moderately strong (at the level of -0.360). Table 10 presents the model fit indices.

Table 10.
Model fit indices

Fit Measures	Value	Status
CMIN/Degrees of freedom	1,399	acceptable
RMR	0,042	acceptable
GFI	0,933	acceptable
AGFI	0,904	acceptable
CFI	0,975	acceptable
RMSEA	0,060	acceptable
PCLOSE	0,329	acceptable

Source: own research.

The values of all fit indices indicate a good fit of the theoretical model to the empirical data. Ultimately, the model adequately reflects the actual structure of the variance-covariance matrix among the analyzed construct components. The path model, along with the estimated (standardized) coefficient, is presented in Figure 2.

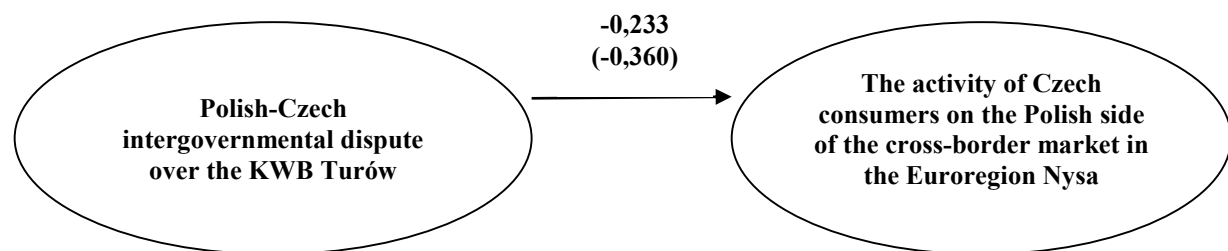


Figure 2. Model with estimated coefficients – for Czech consumers of the Euroregion Nysa.

Source: own research.

It can therefore be concluded that, based on the obtained results, there is no basis to reject the first hypothesis (H1). According to Czech consumers, a higher level of agreement among respondents regarding the negative impact of the KWB Turów dispute on Polish-Czech relations leads to a reduction in the activity of Czech consumers on the Polish side of the cross-border market in the Nysa Euroregion.

3.2. The Impact of the Polish-Czech Intergovernmental Dispute over the Turów Lignite Mine on the Activity of Polish Consumers in the Cross-Border Market of the Nysa Euroregion

Similar analyses (as conducted for respondents from the Czech side) were also carried out for the group of Polish consumers (N = 194). First, a reliability analysis was performed for the first question, which consisted of five test items. For this set of items, the Cronbach's alpha

coefficient was 0.891. This result is satisfactory, and further analysis showed that removing any of the items would not lead to a significant increase in the Cronbach's alpha value (Table 11).

Table 11.
Cronbach's Alpha After Item Deletion

Position Statistics				
Specification	Scale average after removing items	Scale variance after item removal	Total position correlation	Squared multiple correlation
pyt_1.1	9,66	16,714	0,607	0,898
pyt_1.2	10,38	16,001	0,824	0,848
pyt_1.3	10,10	16,482	0,773	0,860
pyt_1.4	10,37	16,583	0,733	0,868
pyt_1.5	9,70	15,393	0,758	0,862

Source: own research.

The reliability analysis showed that all items in the composite scale are strongly correlated with it. Therefore, all analyzed statements should be included in the factor analysis. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy at 0.825 indicates that the data are suitable for factor analysis. Similarly, Bartlett's test of sphericity (451.937, p-value < 0.001) rejects the null hypothesis that the correlation matrix is an identity matrix, confirming that factor analysis is appropriate. Table 12 presents the percentage of explained variance.

Table 12.
Total Explained Variance

Component	Initial eigenvalues			Sums of squared charges after extraction		
	Total	% variance	% cumulative	Total	% variance	% cumulative
1	3,528	70,561	70,561	3,528	70,561	70,561
2	0,663	13,262	83,823			
3	0,334	6,677	90,500			
4	0,300	5,999	96,499			
5	0,175	3,501	100,000			

Method of isolating factors – principal components.

Source: own research.

Assuming that the five analyzed statements constitute a single factor, it was observed that this factor explains 70.561% of the variance in the input data set. Thus, reducing the 5-dimensional set to a single latent factor results in a loss of 29.439% of information. Assuming that variables with factor loadings exceeding 0.5 (in absolute value) should be retained, the final factor loading matrix is presented in Table 13.

Table 13.
Factor Loading Matrix

Component matrix ^a	
Specification	Component 1
pyt_1.2	0,904
pyt_1.3	0,870
pyt_1.5	0,845

Cont. table 13.

pyt_1.4	0,845
pyt_1.1	0,725
Method of isolating factors – principal components.	
a. 1 – number of separated components.	

Source: own research.

The information in Table 14 shows that, for the set of six test items, the Cronbach's alpha coefficient is 0.927. This result is satisfactory, and further analysis indicated that removing any individual item does not lead to a significant increase in the Cronbach's alpha value.

Table 14.
Cronbach's Alpha after Item Deletion

Position Statistics				
Specification	Scale average after removing items	Scale variance after item removal	Total position correlation	Squared multiple correlation
pyt_2.1	17,01	17,500	0,766	0,917
pyt_2.2	16,99	16,424	0,793	0,914
pyt_2.3	16,91	16,721	0,854	0,905
pyt_2.4	16,92	17,029	0,849	0,906
pyt_2.5	17,06	18,414	0,780	0,916
pyt_2.6	16,93	17,829	0,709	0,924

Source: own research.

Assuming that the six analyzed statements constitute a single factor, it was observed that they explain 68.432% of the variance in the input data set. Thus, reducing the 6-dimensional set to a single latent factor results in a loss of 31.568% of the information. Table 15 presents the total explained variance.

Table 15.
Total explained variance

Component	Initial eigenvalues			Sums of squared charges after extraction		
	Total	% variance	% cumulative	Total	% variance	% cumulative
1	4,427	73,787	73,787	4,427	73,787	73,787
2	0,627	10,456	84,243			
3	0,317	5,277	89,520			
4	0,262	4,365	93,885			
5	0,212	3,538	97,423			
6	0,155	2,577	100,000			
Method of isolating factors – principal components.						

Source: own research.

Assuming that the six analyzed statements constitute a single factor, it was observed that this factor explains 73.787% of the variance in the input data set. Thus, reducing the 6-dimensional set to a single latent factor results in a loss of 26.213% of information. The final factor loadings matrix is presented in Table 16.

Table 16.
Factor Loadings Matrix

Component matrix ^a	
Specification	Component
	1
pyt_2.3	0,906
pyt_2.4	0,902
pyt_2.2	0,859
pyt_2.5	0,847
pyt_2.1	0,838
pyt_2.6	0,796
Method of isolating factors – principal components.	
a. 1 – number of separated components.	

Source: own research.

The information in Table 16 indicates that all variables have high, positive factor loadings on the analyzed factor, which is a desirable outcome.

To estimate the impact of the Polish-Czech intergovernmental dispute over the Turów Coal Mine (KWB Turów) on the activity of Polish consumers on the Czech side of the cross-border market in the Nysa Euroregion, the latent variables were incorporated into a structural equation model (SEM). The analysis procedure was identical to that used for the Czech consumers. The developed research model included the factors generated from the conducted analysis. In this model, a path structure was adopted to determine how the Polish-Czech intergovernmental dispute over KWB Turów affects the activity of Polish consumers on the Czech side of the cross-border market in the Nysa Euroregion – Figure 3.

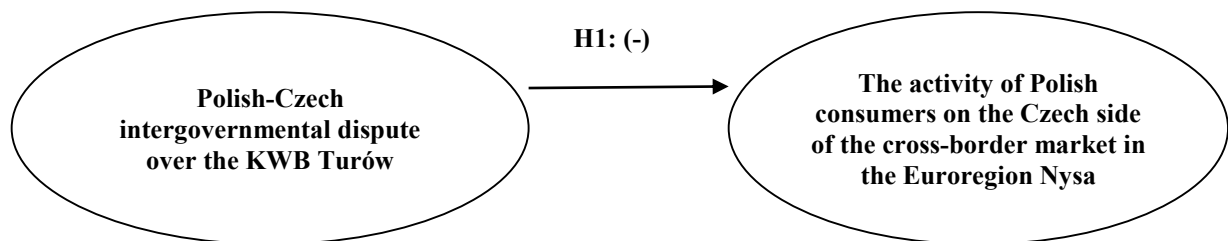


Figure 3. Theoretical model – for Polish consumers of the Nysa Euroregion.

Source: own research.

Hypothesis two (H2) assumes that the PL-CZ intergovernmental dispute over KWB Turów exerted a dampening effect on the activity of Polish consumers on the Czech side of the cross-border market in the Nysa Euroregion. In other words, as the negative perception of Czechs by Poles (triggered by the PL-CZ government dispute over KWB Turów) increases, the willingness of Polish consumers to engage in activities on the Czech side of the Nysa Euroregion cross-border market decreases. The parameters of the estimated model are presented in Table 17.

Table 17.
Model coefficients

Specification			Model coefficient	Standardized coefficient	Standard error	t-statistic	p-value	R-squared
The activity of Czech consumers on the Polish side of the cross-border market in the Euroregion Nysa	<---	Polish-Czech intergovernmental dispute over the KWB Turów	-0,218	-0,241	0,080	-2,717	0,007*	0,058

* statistical significance at the level of 0.05.

Source: own research.

The information in Table 17 indicates that the PL-CZ intergovernmental dispute over KWB Turów has a negative (dampening) effect on the activity of Polish consumers on the Czech side of the cross-border market in the Nysa Euroregion. This relationship is statistically significant, though weak (at the level of -0.241). Table 18 presents the model fit indices.

Table 18.
Model fit indices

Fit Measures	Value	Status
CMIN/Degrees of freedom	1,183	acceptable
RMR	0,054	acceptable
GFI	0,966	acceptable
AGFI	0,913	acceptable
CFI	0,996	acceptable
RMSEA	0,036	acceptable
PCLOSE	0,663	acceptable

Source: own research.

The values of all fit indices indicate a good fit of the theoretical model to the empirical data. Ultimately, the model appropriately reflects the actual structure of the variance-covariance matrix among the analyzed construct components. The path model, along with the estimated coefficient (standardized coefficient), is presented in Figure 4.

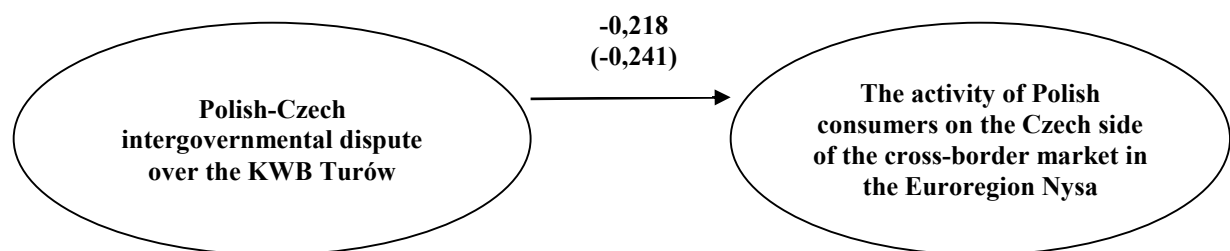


Figure 4. Model with estimated coefficients – for Polish consumers of the Nysa Euroregion.

Source: own research.

Considering the obtained results, it can therefore be concluded that there is no basis to reject the second hypothesis (H2). According to Polish consumers, an increasing consensus regarding the negative impact of the KWB Turów dispute on relations between Poles and Czechs leads to a reduction in the activity of Polish consumers on the Czech side of the cross-border market in the Nysa Euroregion.

4. Discussion

In summary, the results indicate that the Polish-Czech dispute over the Turów lignite mine exerted a discouraging, negative impact on consumer activity in the cross-border market of the Nysa Euroregion, on both the Czech and Polish sides. Among Czech consumers, this impact was moderately strong, while among Polish respondents it was weaker, though still statistically significant. The influence of the conflict on consumer behavior in the region was most evident in the form of increased reluctance toward cross-border trade. Empirical findings (interviews and surveys) suggest that some residents of the Nysa Euroregion avoided crossing the border to the neighboring country to shop or use services during the dispute (Bohm, Nowotny, Kurowska, 2024; Wróblewski et al., 2023). In practice, local entrepreneurs on both sides of the border observed a decline in the number of cross-border customers—particularly in retail and gastronomy. There were also incidental cases of social tension. For example, in the Polish town of Bogatynia, a local councilor distributed leaflets during the dispute, calling on Czech consumers to show restraint in their purchases, arguing that excessive buying of products (e.g., butter, dairy, vegetables, meat) by Czech customers was “leaving Polish families with empty shelves” (blesk.cz, 2022).

The dispute thus became, for some consumers in the cross-border market, a catalyst for negative emotions and a symbol of the “bad faith” of consumers from the other side of the border. Slogans even emerged about a “Czech-Polish war over Polish food,” and insulting labels were used to describe Czech consumers shopping in Poland (“Czech locusts”) (blesk.cz, 2022). Such incidents led to shifts in consumer attitudes and behaviors on both sides of the border—from a simple desire to buy cheaper goods in the neighboring country to defensive and protectionist stances. This is confirmed both by existing literature and by the findings of other scholars. In general, the evidence shows that intergovernmental disputes can have serious consequences at the level of consumer behavior, mainly by undermining trust and increasing uncertainty. In European border regions, political conflicts, disputes over natural resources, and intergovernmental tensions have also been shown to negatively affect cross-border markets, including inducing undesirable consumer behavior. Research on the German-Polish border, for instance, demonstrated that intergovernmental disputes weaken trust in cross-border products and reduce tourism as well as local trade (Schulz et al., 2009).

These mechanisms were also described by Zeugner-Roth, Žabkar, and Diamantopoulos (2015). Their research, conducted in a shopping mall in Japan during the Sino-Japanese intergovernmental dispute over the Senkaku Islands (Chinese name: Diaoyu) in the East China Sea, revealed that during the conflict Japanese consumers’ hostility toward Chinese products intensified significantly, and negative emotions clearly influenced their purchasing decisions. Importantly, the Japanese studies indicate that consumer attitudes worsened due to two mechanisms:

- past-oriented animosity, rooted in collective memory and the history of conflicts and grievances (e.g., Japanese occupation of China in the 20th century), which has long-term effects on consumer attitudes,
- situational animosity, triggered by the ongoing political conflict and media tensions, which can strongly and immediately affect consumer emotions and behaviors.

The Japanese case shows that under heightened interstate conflict, consumers not only declare more negative attitudes toward products from the “enemy” country but also actually reduce purchases of such goods, regardless of their quality, price, or availability. A mechanism of consumer boycott driven by national animosity is at work here. Similar to the findings in the Polish-Czech borderland, in Japan both historical and current animosities significantly reduced consumer willingness to purchase Chinese products, with current, situational emotions having a stronger effect than historical grievances. Once the dispute ended, the level of hostility declined, and consumer decisions and product evaluations returned to more objective assessments, demonstrating the temporary nature of the conflict’s effects.

Proffen and Jürgensmeier (2024) likewise showed that deteriorating relations between the United States and China—caused by technological disputes, accusations by some American politicians concerning the COVID-19 pandemic, as well as the trade war and tariff policies—significantly reduced the number of visits by American consumers to Chinese restaurants in the United States. This phenomenon is linked to consumer ethnocentrism (a tendency to favor domestic products during conflicts) and social pressure to engage in forms of boycott.

The reviewed studies confirm that intergovernmental political and economic disputes can have a clear, though temporary, impact on consumer activity. They highlight the importance of monitoring both historical and current animosities to better understand the mechanisms shaping cross-border market behavior. In the context of the Nysa Euroregion—where social and economic relations were/are strongly influenced by the local dispute over the Turów mine—this points to the necessity of continuous monitoring of public sentiment and implementing mediation activities aimed at improving both current trust and long-term relations between the communities sharing the border.

The relationship discussed in this article aligns with a broader theoretical framework based on social identity theory (Tajfel, Turner, 1979; Wróblewski, 2020, 2024). The Turów dispute reinforced moments of strong identification with one’s national group (especially in the Czech Republic), which increased ethnocentrism and negative emotions toward the out-group. Research on consumer ethnocentrism confirms that ethnocentrism and the related attitudes play a key role in consumer choices (including in cross-border markets), particularly in contexts of tensions and disputes (Shimp, Sharma, 1987; Prince et al., 2020). Thus, patriotic and ethnocentric attitudes can amplify the discouraging effect of intergovernmental disputes, limiting consumer activity in the cross-border market and thereby reducing demand for products from the disputing country (while reinforcing domestic preferences).

The literature further shows that high levels of nationalism and national belonging intensify consumer ethnocentrism—the tendency to favor “one’s own” products at the expense of foreign ones. Balabanis et al. (2001) demonstrated that in societies with heightened nationalism, consumer ethnocentrism tends to rise. Similarly, Balabanis and Siamagka (2022), analyzing data from 57 countries, found that consumer ethnocentrism is a universal phenomenon, driven primarily by cultural factors and the degree of ethnic diversity. Moreover, their findings indicate that high levels of ethnocentrism significantly restrict the import of consumer goods. At the same time, Fernández-Ferrín et al. (2015) emphasize that animosity and consumer ethnocentrism are distinct constructs, each with unique antecedents and consequences for consumer behavior. While historical conflicts foster animosity, ethnocentrism is more strongly influenced by current intergovernmental disputes. For example, Sun et al. (2021) describe how a territorial dispute between China and Japan triggered a nationwide boycott of Japanese cars in China. As a result, the market share of Japanese brands plummeted, mainly to the benefit of Chinese producers and other foreign competitors.

Findings from the Nysa Euroregion study also revealed varying degrees of discouragement among Czech and Polish respondents, with the effect being stronger among Czech consumers. Several factors may explain this. First, the Czech community in the Nysa Euroregion was more sensitive to environmental concerns and perceived threats to quality of life related to the Turów mine. Second, the media and public narratives in the Czech Republic placed greater emphasis on potential risks, further amplifying negative attitudes and limiting consumer activity. Third, cultural and historical factors may have heightened Czech society’s sensitivity to environmental issues, explaining the greater degree of discouragement in their cross-border activity. While environmental sensitivity appears to be a key factor explaining the stronger discouraging effect observed among Czech respondents, it should not be treated as the sole explanatory dimension. Alternative factors may also have contributed to the observed differences between Polish and Czech consumers. One such factor is purchasing power, as Czech households in the border region generally exhibit higher average income levels, which may translate into more discretionary cross-border consumption and, consequently, a greater responsiveness to political or social disruptions.

Another relevant dimension concerns media exposure and narrative framing. Czech media coverage of the Turów dispute was often more intensive and framed the issue as a direct threat to national environmental security and local livelihoods, which may have amplified negative perceptions among Czech consumers. In contrast, Polish media discourse tended to emphasize economic stability and employment concerns, potentially mitigating the impact of the conflict on consumer attitudes. Although these dimensions were not directly measured in the present study, they offer plausible complementary explanations that should be explored in future research.

In conclusion, the findings confirm that emotions and group identification play a crucial role in shaping consumer behavior during periods of international disputes. Factors such as ethnocentrism, historical animosities, national identity, and cosmopolitan attitudes can determine the extent to which an intergovernmental conflict influences consumer purchasing decisions in the cross-border market. The comparative interpretation of the findings should also account for broader contextual differences between the Polish and Czech sides of the border. Despite their geographical proximity, the two groups operate within distinct institutional, socio-economic, and cultural contexts that shape consumer attitudes and reactions to political disputes. As a result, the observed asymmetries should not be interpreted as universal patterns of consumer response but rather as context-dependent outcomes embedded in a specific borderland setting.

By adopting this nuanced comparative perspective, the study avoids overgeneralization and underscores the importance of local context in understanding how intergovernmental disputes affect cross-border consumer behavior. This approach strengthens the theoretical contribution of the paper by highlighting that political conflicts do not translate into consumer responses uniformly, even within a single integrated cross-border market.

5. Conclusion

In light of the conducted research, it can be stated that the Polish-Czech dispute over the Turów lignite mine had a clear, though varied in intensity, negative impact on consumer activity in the cross-border market of the Euroregion Nysa. On both the Czech and Polish sides, a reduction in its functioning was observed, which confirms earlier theories and studies indicating that international conflicts generate uncertainty and weaken social trust, temporarily leading to a decrease in cross-border consumer activity. According to previous research on borderlands, the impact of intergovernmental disputes on consumer behavior is a widespread phenomenon, although its intensity depends on the specific features of the region, the nature of the conflict, and the degree of social integration. The results of the study conducted on the Polish-Czech border confirm this general trend, while emphasizing that conflicts concerning natural resources and environmental protection may trigger stronger destimulating reactions in communities that are more environmentally sensitive and more strongly identified with the region.

It is also worth emphasizing that the results of this study have important practical implications. Both governments and local economic actors should take into account that tensions, disputes, and political conflicts can significantly reduce consumer activity in border regions, which in turn affects economic development and cross-border cooperation. In the future, it is therefore necessary to carry out more thoughtful communication activities,

which, instead of escalating the dispute, lead to mitigating its negative effects and building mutual trust among communities sharing a common border.

Despite the significant conclusions that emerged from the study, several of its limitations should be pointed out. First, the research sample was based on the method of voluntary selection of respondents, which by its very nature limits the possibility of full representativeness of the results. Respondents were selected from among the inhabitants of the Bogatynia municipality and several selected Czech localities, which does not guarantee full reflection of the entire population of the Euroregion Nysa, estimated at about 1.1 million inhabitants. Second, the data were collected using a paper questionnaire, which exposes the study to limitations typical of survey methods, such as distortions resulting from the tendency to provide socially acceptable answers or unconscious errors in assessment. Despite careful verification and the rejection of incomplete or erroneous questionnaires, some methodological errors may still have occurred. Third, the study focused exclusively on individuals who were aware of the existence of the dispute over the Turów mine, which may have influenced the selection of respondents and introduced a selection effect. Less engaged individuals or those unfamiliar with the details of the conflict might have perceived and reacted differently, which may have reduced the full picture of the dispute's impact on consumer behavior. Fourth, the operationalization of the components related to the dispute, based on selected statements developed from expert interviews, may not have accounted for the full scope of social and psychological aspects of the conflict's impact. In future studies, the use of qualitative methods or other measurement tools could be considered to provide deeper insight into this issue.

In light of the obtained results and the limitations of the conducted study, further research is necessary in order to better understand the impact of intergovernmental disputes on consumer behavior in European borderlands. It is recommended to carry out longitudinal studies that would allow for the assessment of the long-term effects of political conflicts on consumer activity on both sides of the border. Such an approach would also make it possible to analyze changes over time and identify factors conditioning the durability of destimulating effects. It would be particularly interesting to expand the research to other European borderlands in order to compare the consequences of intergovernmental disputes in different cultural, social, and economic contexts. Such an analysis would allow for the identification of universal mechanisms as well as region-specific conditions. Finally, future studies may also take into account other aspects of the impact of disputes on the cross-border market, such as the influence on investments, entrepreneurship development, or cultural exchange, which would enable a comprehensive understanding of the consequences of intergovernmental disputes for border regions.

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ARTIFICIAL INTELLIGENCE AS A CATALYST FOR THE REDEFINITION OF PROCESSES IN ORGANIZATIONS

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Purpose: This paper examines how artificial intelligence (AI) redefines the structure and execution of supporting business processes, with a focus on micro-level process changes affecting workflows, roles, and efficiency.

Design/methodology/approach: The study uses a qualitative, exploratory approach combining a literature review with multiple case studies. Two AI implementations were analyzed: Excel translation automation in a financial corporation and AI-driven procurement automation in a commercial organization. The analysis applies process-before/after comparisons using BPMN, pattern matching, and cross-case synthesis.

Findings: AI implementation appears to enable reconfiguration of supporting business processes, including shorter cycle times, simpler process structures, fewer actors, and reduced manual errors. Employee roles shift from execution to supervision and analytical tasks, while process maturity appears to emerge as a key enabler of effective transformation.

Research limitations/implications: The qualitative design and limited number of cases restrict generalizability. Future research should adopt longitudinal designs and include a wider range of industries and process maturity levels.

Practical implications: AI should be implemented as a process transformation initiative rather than isolated automation. Organizations should prioritize mature supporting business processes and invest in analytical and supervisory competencies, achieving improved efficiency, data quality, and scalability.

Social implications: AI adoption reduces routine work and increases demand for knowledge-intensive roles, influencing job design and skill development.

Originality/value: The paper offers a micro-analytical, process-centric perspective on AI-driven transformation of supporting business processes, contributing empirical evidence to BPM and digital transformation research.

Keywords: Artificial intelligence; supporting business processes; business process management; process maturity; dynamic capabilities.

Category of the paper: Literature review; Case study.

1. Introduction

The rapid development of artificial intelligence (AI) has become an important driver of organizational change, affecting not only strategic decision-making but also the execution of business processes (Brynjolfsson, McAfee, 2017). Recent holistic reviews further underline that AI technologies underpin transformations across virtually all sectors, yet empirical evidence on micro- level process changes remains scarce (Rashid, Kausik, 2024). Within the field of business process management (BPM), AI is increasingly discussed as an enabling technology for automating repetitive tasks, improving information quality, and enhancing workflow coordination.

However, existing research predominantly adopts a macro-level perspective, focusing on strategic or organizational implications of AI adoption, while micro-level evidence on AI-induced process transformation remains limited. This gap is particularly visible in the context of supporting business processes, which, although not directly linked to customer value creation, are critical for organizational stability and are frequently selected as initial candidates for AI implementation.

This study addresses this gap by examining how AI reshapes the structure and execution of supporting business processes and by exploring the associated operational effects and changes in role allocation. Based on a comparative analysis of two supporting business processes in different organizational contexts, the study is guided by the following research questions:

- RQ1. What structural changes occur in supporting business processes following AI implementation, particularly in terms of activities, sequencing, and actors?
- RQ2. What operational effects are observed in supporting business processes following AI implementation, as reflected in changes to process cycle time, error-prone activities, and information flow?
- RQ3. How does AI-driven transformation of supporting business processes alter employee roles and task allocation within the process architecture?

The study aims to explain how AI influences supporting business processes and what these changes imply for process execution, using a comparative case- based design and BPMN before–after models to capture micro- level dynamics. It contributes by detailing concrete mechanisms of AI- enabled change in supporting business processes, focusing on structural, procedural, and role- related modifications visible in process models and performance metrics, rather than only on firm- level or sector- level outcomes.

The remainder of the paper is structured as follows. Section 2 reviews the relevant literature on AI, supporting business processes, process maturity, and dynamic capabilities. Section 3 presents the research methodology. Section 4 reports the empirical findings. Section 5 discusses the results in relation to prior research, and Section 6 concludes the paper with implications, limitations, and directions for future research.

2. Theoretical background

2.1. Artificial Intelligence in Business Process Management (AI–BPM)

Artificial intelligence (AI) has become a significant driver of change in business process management (BPM), extending traditional approaches to automation toward intelligent, data-driven process execution and control. Classical BPM and reengineering literature emphasized the transformative role of information technology in eliminating non-value-adding activities and redesigning process structures (Davenport, 1993; Hammer, Champy, 1993; Harmon, 2002). While comprehensive overviews document AI's pervasive role in transforming industries from manufacturing to healthcare and finance (Rashid, Kausik, 2024), far less is known about how these technologies reconfigure specific supporting business processes. Contemporary AI-BPM research builds on this foundation by conceptualizing AI as embedded across the BPM lifecycle, particularly in process execution, monitoring, and decision support (Dumas et al., 2018; Fettke, Di Francescomarino, 2025).

Recent anchor studies highlight that AI contributes not only to task automation but also to process logic reconfiguration, including automated decision points, dynamic routing, and intelligent orchestration of activities (Abbasi et al., 2024; Weinzierl et al., 2024). Explainable and fully automated process redesign approaches demonstrate how AI can reshape end-to-end process structures rather than optimize isolated tasks, supporting a shift from rule-based automation toward adaptive process execution (Weinzierl et al., 2024). Despite these advances, much of the empirical literature remains focused on macro-level outcomes such as productivity or firm performance, leaving micro-level process transformations insufficiently explored (Brynjolfsson, McAfee, 2017; Dwivedi et al., 2021).

From a work perspective, AI–BPM literature consistently points to work augmentation rather than full substitution of human labor. Machine learning systems increasingly perform routine information processing, while human actors transition toward supervisory, analytical, and exception-handling roles embedded within process architectures (Brynjolfsson, Mitchell, 2017; Jarrahi, 2018). Employee perception studies further confirm that smart technologies reshape task allocation and role positioning within processes, reinforcing the relevance of micro-level process analysis (Brougham, Haar, 2018).

2.2. Supporting business processes and Process Maturity

Business processes are commonly classified into operational, supporting, and managerial processes (Davenport, 1993). While operational processes directly create customer value, supporting business processes—such as HR, IT, finance, or logistics—provide critical resources and coordination mechanisms that enable core activities. Although supporting business processes do not generate direct customer value, they are essential for organizational

stability and the effective functioning of operational processes (Dumas et al., 2018; Winiarska, Kizielewicz, 2023).

Due to their standardized structure, repetitive activities, and intensive information processing, supporting business processes are frequently selected as early candidates for AI-enabled automation, including robotic process automation and intelligent document processing (Willcocks et al., 2016). AI-BPM research indicates that the depth of AI-induced transformation is contingent on process maturity, defined as the degree of standardization, documentation, monitoring, and measurement of process execution (Rosemann, vom Brocke, 2010). Focusing on supporting business processes does not imply lower analytical relevance; rather, it enables clearer observation of AI-induced micro-level reconfiguration due to higher standardization and formalization.

Anchor studies emphasize that mature processes provide the transparency and data availability required for embedding AI into process execution logic rather than limiting its use to isolated task automation (Fettke, Di Francescomarino, 2025). Empirical evidence suggests that in high-maturity contexts, AI can facilitate deeper process reconfiguration, including the elimination of non-value-adding activities, reduction of handovers, and tighter integration of information flows across organizational units (Mikalef, Gupta, 2021; Abbasi et al., 2024; Weinzierl et al., 2024). In contrast, low-maturity processes typically experience fragmented automation with limited structural impact. Despite their suitability as an empirical context, supporting business processes remain underrepresented in micro-level AI-BPM research.

2.3. Dynamic Capabilities and Micro-Level Process Change

Dynamic capabilities theory provides a robust lens for interpreting AI-enabled process transformation. Dynamic capabilities refer to an organization's ability to sense opportunities, seize technological potential, and reconfigure operational routines in response to environmental change (Teece, 2018). While early research focused primarily on firm-level and strategic outcomes, more recent studies emphasize the importance of micro-foundations, including business processes through which adaptation is enacted.

From this perspective, AI functions as an enabling mechanism that supports process-level transformation by embedding automated information processing and decision support into existing workflows (Mikalef, Gupta, 2021). Anchor papers explicitly link AI-enabled BPM to dynamic capabilities by demonstrating how intelligent orchestration and process redesign contribute to the reconfiguration of operational routines (Abbasi et al., 2024; Weinzierl et al., 2024).

Micro-level changes, such as simplified process structures, automated information flows, reduced handovers, and redefined human roles, constitute observable manifestations of organizational adaptability. Importantly, AI does not generate dynamic capabilities autonomously; its transformative potential depends on process maturity, clarity of routines, and alignment between technology and human roles (Fettke, Di Francescomarino, 2025).

Due to their context-dependent and process-specific nature, such mechanisms are best examined using qualitative, case-based research designs (Eisenhardt, 1989; Yin, 2018).

3. Methodology

3.1. Research Design and Methods

This study adopts a qualitative, exploratory research design aimed at reconstructing micro-level changes in supporting business processes following AI implementation. The approach is descriptive–analytical and appropriate for research areas where prior empirical evidence remains limited, particularly with regard to AI-induced process transformation at the operational level (Eisenhardt, 1989; Yin, 2018).

To address the research questions, a qualitative multi-method strategy was applied. First, a narrative literature review was conducted as a methodological component to synthesize dominant theoretical perspectives on artificial intelligence in business process management (AI-BPM), supporting business processes, process maturity, and micro-level process change.

The review followed a transparent, theory-oriented search procedure, drawing on peer-reviewed publications indexed in Scopus and Web of Science. The search focused on publications from 2020 to 2025 and employed keywords such as artificial intelligence, business process management, supporting processes, process reconfiguration, and dynamic capabilities. Studies were included if they explicitly addressed AI-enabled process transformation or micro-level changes in organizational processes.

The narrative approach was selected due to the conceptual heterogeneity of the AI-BPM field and the exploratory nature of the study, which makes systematic aggregation of findings inappropriate. Rather than aiming for exhaustiveness, the review focused on identifying conceptually influential and widely cited contributions that informed the theoretical framing and empirical design of the study.

Second, a multiple case study approach was employed to enable in-depth investigation of AI-enabled process transformation in real organizational settings. Following the logic of theoretical replication, cases were selected for their analytical relevance rather than representativeness, allowing for cross-case comparison and analytical generalization (Eisenhardt, 1989; Yin, 2018).

Third, process-level analysis based on BPMN models was used as a core analytical method. Before–after comparison of BPMN representations enabled systematic identification of changes in process structure, task sequencing, automation level, and role allocation following AI implementation. The use of BPMN ensured a consistent analytical language across cases and supported detailed reconstruction of micro-process changes.

The combination of these methods enabled methodological triangulation between theory-oriented synthesis, empirical case analysis, and process modeling, enhancing the robustness and transparency of the research design.

3.2. Data Sources and Data Analysis

Empirical data were collected from two organizations operating in different industry contexts. In each case, the unit of analysis was a single supporting business process examined independently in its pre- and post-AI implementation state. The analyzed processes were characterized by a high degree of formalization, intensive information processing, and substantial human–system interaction.

Case selection followed a purposive sampling strategy based on the following criteria:

1. relevance of the process for organizational support activities,
2. clear potential for AI-enabled automation and process reconfiguration,
3. availability of comparable process documentation before and after AI implementation.

An overview of the studied cases is provided in Table 1.

Table 1.
Studied cases

Case	Organization	Process	AI Technology
A	International financial corporation	Excel file translation	NLP + workflow automation
B	Large retail organization	Purchasing process	AI-driven demand forecasting + OCR/NLP

Source: own elaboration.

Data sources included operational documentation, process architecture descriptions, and BPMN process models depicting process execution before and after AI implementation. Additional process-related indicators were derived from organizational records and expert validation, including indicative process cycle times, number of process steps, number of involved actors, and main sources of manual errors. Where system logs were incomplete, expert estimates provided by process owners were used to complement available data; therefore, some reported values should be interpreted as indicative rather than statistically representative.

Data analysis followed a three-stage procedure. First, before–after process comparison was conducted using BPMN models to identify changes in task structure, sequencing, automation level, and role allocation. Second, within-case analysis was performed to document process-level changes separately for each organization. Third, cross-case synthesis was applied to identify recurring patterns of AI-induced transformation across both cases.

The analysis focused on observable structural, procedural, and role-related changes in supporting business processes. Quantitative indicators, such as cycle time reduction or reduction in actor involvement, were used to illustrate the magnitude of observed changes, while the primary emphasis remained on qualitative reconstruction of process execution logic.

The interpretation of findings in relation to BPM and dynamic capabilities literature is presented in the Discussion section.

4. Empirical Findings

4.1. Case A – Automation of Excel Translation in a Financial Corporation

Case A (Appendix, Figure 1) concerns a large financial corporation collaborating extensively with clients in the Asia-Pacific region. Translating Excel files (between Asian languages and English) was critical for operational information flow, as files contained both descriptive content and complex formulas that needed to be preserved. Delays in this process impeded timely client responses and subsequent analytical work. Process Steps Before and After AI Implementation are presented in Table 2.

Before AI implementation, translation was entirely manual, performed by internal and external translators. Files were repeatedly passed between units, increasing the risk of formatting errors and content inconsistencies. Average processing time per file was 2-3 days, with low standardization of work.

The solution implemented Alteryx Designer with Intelligence Suite, automating data flows and applying AI for content extraction and processing. Key functionalities included:

- OCR and text extraction from files (Image/PDF to Text module).
- Content analysis and classification via text mining.
- Automated processing, structuring, and transformation using rule-based workflows and Python scripts.
- Terminology unification and content generation through Generative AI integrated with language models.

Table 2.

Case A – Process Steps Before and After AI Implementation

Step	Pre-AI (Manual)	Post-AI (Automated)	Key AI Value
1	File receipt & registration	Automatic file capture by workflow	Eliminates manual handover
2	Manual scope analysis	Automatic structure & metadata extraction	Speed & completeness
3	Manual translation	NLP translation with glossaries	Terminology consistency
4	Manual formula reconstruction	Automatic formula mapping	Error-free references
5	Manual formatting correction	Automatic content & format merge	Maintains layout
6	Verification by another employee	Automatic validation + exception routing	Reduces human effort
7	Business testing & adjustments	QA only for exceptions	Eliminates iterative cycles
8	Finalization & distribution	Automatic publishing & logging	Full auditability & speed

Source: own elaboration.

The automated workflow eliminated manual copying, reduced errors, and drastically shortened processing time. Human roles shifted from execution to oversight of data quality. Post-implementation, the average file translation took only a few minutes. The process became scalable, reliable, and focused on control and interpretation rather than manual operation.

4.2. Case B – AI in Purchasing Process Automation in a Retail Organization

Case B (Appendix, Figure 2) analyzed a purchasing process in a large retail organization, where timely ordering is critical for product availability and cost optimization. Prior to AI, purchasing required extensive manual work: employees monitored inventory and sales data, created orders, and entered information into ERP systems. Process Steps Before and After AI Implementation are presented in Table 3. Logistics and financial documents were handled separately, risking delays and errors.

AI implementation included predictive algorithms analyzing sales history and demand seasonality, combined with automatic document recognition for real-time classification and data entry. Key AI components:

- OCR for data extraction from purchase documents (orders, delivery notes, invoices).
- NLP for field recognition, document classification, and content validation.
- Demand forecasting model generating orders automatically.
- Automated document matching linking orders, invoices, and delivery notes.
- Workflow orchestration and API integration enabling automatic information flow between the purchasing system and suppliers.

Table 3.

Case B – Process Steps Before and After AI Implementation

Step	Pre-AI (Manual)	Post-AI (Automated)	Key AI Value
1	Manual request reporting	AI proactive alerts	Eliminates response delays
2	Manual demand forecasting	Automatic prediction	Accurate forecasts, no Excel sheets
3	Manual order creation	Automated order generation	Reduces errors & time
4	Manual dispatch & confirmation	API integration, real-time status	Process transparency
5	Manual data entry from documents	OCR + NLP automated extraction	Eliminates transcription errors
6	Manual document matching	Automated matching (order–invoice–delivery)	Faster reconciliation
7	Frequent exception handling	Human only for exceptions	Reduces escalations
8	Process closure & posting	Automatic audit & reporting	Shortened reconciliation time

Source: own elaboration.

Manual tasks were substantially reduced, shortening process duration by 60-80%. Employees transitioned to exception handling and system oversight, enabling data-driven decisions and enhancing organizational adaptive capacity.

5. Results

The empirical analysis followed a three-stage procedure: (1) before–after comparison of process models, (2) identification of recurring patterns across cases, and (3) cross-case synthesis. This section reports the observed changes in supporting business processes following AI implementation, without extending into theoretical interpretation.

Table 4 presents a comparative overview of key process metrics before and after AI implementation in both cases.

Table 4.
Comparison of Key Process Metrics Before and After AI Implementation

Metric	Case A – Excel Translation	Case B – Purchasing	Observed Process-Level Effect
Cycle time	2-3 days → 5-10 minutes (approx. –95–98%)	3-7 days → < 1 hour (approx. –95–98%)	Elimination of waiting time and manual coordination
Process structure	8 → 6 steps (–25%)	8 → 6 steps (–25%)	Reduction of non-value-adding activities and handovers
Actor involvement	3 → 1 actor	6 → 1 actor	Centralization of execution with distributed supervision
Error exposure	Manual translation → automated NLP	Manual entry → automated validation	Shift from human error-prone tasks to system-level controls
Human role	Operational execution → supervision and analytics	Manual input → exception handling and oversight	Reallocation of human effort toward higher-level activities

Source: own elaboration.

The empirical analysis shows observable changes in both operational performance indicators and the structure execution logic of the analyzed supporting processes. Across both cases, AI-enabled automation reduced structural complexity by eliminating manual tasks and consolidating execution roles. Process flows became more compact, with fewer handovers and reduced exposure to delay- and error-prone activities.

Before–after analysis of BPMN models further revealed systematic changes in role allocation. Tasks previously performed manually—such as data entry, translation, and document verification—were automated, while human involvement shifted toward supervision, exception handling, and validation. In parallel, information handling within the processes changed through the reduction of data duplication and transcription points and increased consistency of information flows.

Despite differences in organizational context and process type, cross-case synthesis revealed recurring patterns of AI-induced transformation. Both cases exhibited simplified process structures, increased system autonomy in routine execution, and implementation within standardized and formally documented supporting processes. These recurring patterns were observed across both cases at the micro-process level.

The observed effects of AI implementation can be grouped into three interrelated empirical dimensions: **structural effects**, reflected in simplified process design and reduced actor involvement; **procedural effects**, manifested in shorter process cycles and reduced exposure to manual errors; and **role-related effects**, involving the reallocation of human effort toward supervision, exception handling, and analytical activities.

Together, these findings provide empirically grounded answers to the research questions, summarized in Table 5.

Table 5.
Research Questions, Findings, and Implications

RQ	Finding	Theoretical Implication	Practical Implication
RQ1	Process reconfiguration rather than isolated automation	AI contributes to changes in operational logic	Design AI deployment as a process transformation initiative
RQ2	Simplified process structure, fewer error-prone activities, improved resilience	AI strengthens process-level capabilities	Prioritize standardized and mature processes for AI deployment
RQ3	Shift toward supervisory and analytical roles	Supports the concept of work augmentation	Invest in process, digital, and analytical skills

Source: own elaboration.

The interpretation of these findings in relation to BPM and dynamic capabilities literature is presented in the Discussion section.

6. Discussion

The findings show that artificial intelligence reshapes supporting business processes not only through task automation but through structural and logical process reconfiguration.

The empirical results reported in the Results section document observable micro-level changes in process structure, execution logic, and role allocation, without implying any direct measurement of organizational capabilities.

The observed micro-level changes can be interpreted as process-level manifestations of broader AI-driven industrial transformation described in the Industry 4.0/5.0 literature (Rashid, Kausik, 2024).

The conceptual model presented in Figure 3 specifies three micro-level dimensions of change—process logic, data handling, and role transformation—and links them to process maturity in supporting business processes. The model synthesizes recurring empirical patterns identified across the analyzed cases, including fewer handovers, centralized execution with distributed supervision, and a shift toward AI-supported exception handling in back-office contexts.

In both cases, AI implementation led to simplified workflows, shorter execution cycles, and performance gains stemming primarily from process redesign consistent with core BPM principles. These effects were observed at the level of process structure and execution and are summarized in Table 6, which synthesizes the micro-level effects of AI implementation in supporting business processes.

Table 6.

Micro-Level Effects of AI Implementation in Supporting Business Processes

Change Dimension	AI Implementation Effects
Structural	Fewer process steps and actors; streamlined workflows
Procedural	Shorter operational cycles; reduced exposure to manual errors
Competency	Shift toward supervision and analytical activities; increased process oversight

Source: own elaboration.

These results are consistent with classical BPM redesign principles (Davenport, 1993; Hammer, Champy, 1993) and extend them into an AI-enabled context. Rather than radical reengineering, the cases illustrate incremental yet deep reconfiguration embedded within existing process structures, supporting recent AI-BPM research that emphasizes intelligent orchestration over isolated automation (Fettke, Di Francescomarino, 2025).

Process maturity emerged as a key boundary condition for AI-driven transformation. The empirical cases indicate that standardized and well-documented supporting business processes provide favorable conditions for embedding AI at the level of process logic, reinforcing BPM maturity frameworks (Rosemann, vom Brocke, 2010) and research on AI capability development (Mikalef, Gupta, 2021).

AI implementation also altered human involvement in supporting business processes. Consistent with the augmentation-of-work perspective (Brynjolfsson, Mitchell, 2017; Jarrahi, 2018), employee roles shifted toward supervision and analytical activities. Importantly, these role changes emerged as consequences of process redesign rather than as outcomes of explicit human resource interventions, aligning with prior research on technology-induced role transformation (Brougham, Haar, 2018).

From a dynamic capabilities perspective, the observed process transformations can be interpreted as micro-level manifestations of organizational adaptability. However, it should be emphasized that dynamic capabilities are not directly measured in this study and are employed solely as an interpretative lens to contextualize the observed process-level changes, rather than as constructs subjected to theory testing (Teece, 2018).

The integration of structural, procedural, and role-related changes is synthesized in the conceptual model of AI-enabled supporting business process transformation (Figure 3). The model serves as an analytical framework that explains how AI-enabled reconfiguration may emerge under conditions of sufficient process maturity, rather than as a prescriptive or universally generalizable solution.

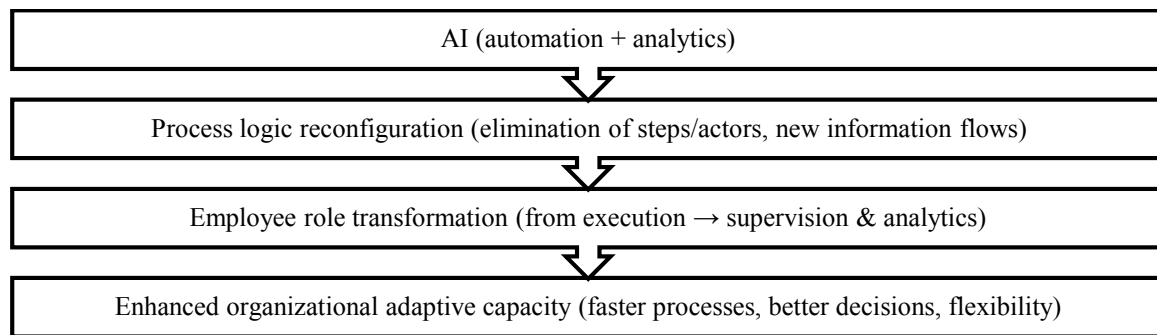


Figure 3. Model of Supporting Business Process Transformation through AI.

Source: own elaboration.

The model is specifically tailored to supporting business processes, where high standardization, intensive information processing, and multi-actor coordination make reductions in handovers and actor involvement particularly visible indicators of AI-enabled reconfiguration.

Overall, this study contributes to AI-BPM research by shifting the analytical focus from isolated task automation to micro-level process reconfiguration in supporting business processes, providing empirically grounded insights into how AI reshapes process execution logic and work organization.

7. Conclusions and Contributions

7.1. Overall Conclusions

This study examined the impact of artificial intelligence on supporting business processes from a micro-process perspective using a qualitative, case-based research design. The findings demonstrate that AI implementation is associated with changes not only in operational efficiency but also in process structure, execution logic, and role allocation. Across the analyzed cases, AI-enabled solutions contributed to simplified process flows, reduced reliance on manual coordination, and a shift of human work toward supervisory and analytical activities. The results further indicate that process maturity plays an important contextual role in shaping the scope and effectiveness of AI-driven transformation. Overall, the study contributes to the business process management literature by providing micro-level, empirically grounded evidence on how artificial intelligence reshapes supporting business processes beyond isolated task automation.

7.2. Practical Implication

For practitioners, the findings suggest that AI initiatives in supporting business processes should be approached as process transformation projects rather than isolated automation efforts. Organizations are likely to benefit most from deploying AI in processes that are already standardized, transparent, and measurable. Additionally, managerial attention should be directed toward redesigning roles and governance mechanisms to support increased system autonomy and effective human oversight.

7.3. Study Limitations

This study has several limitations. First, it is based on two case studies, which constrains the generalizability of the findings. Second, the observation period was relatively short, limiting insights into long-term effects, particularly with respect to organizational learning and cultural change. Third, conclusions regarding employee competencies are based on inferred role changes rather than direct empirical measurement. As a result, conclusions regarding role and competency changes should be interpreted as inferences from process models and performance data rather than from self-reported experiences.

7.4. Future Research Directions

Future research could address these limitations by adopting longitudinal designs, incorporating interviews or ethnographic methods to examine competency development, and comparing different types of AI technologies across varying levels of process maturity. Further investigation into less formalized supporting business processes may also enhance understanding of the boundaries of AI-enabled process transformation.

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Appendix

BPMN models of case studies

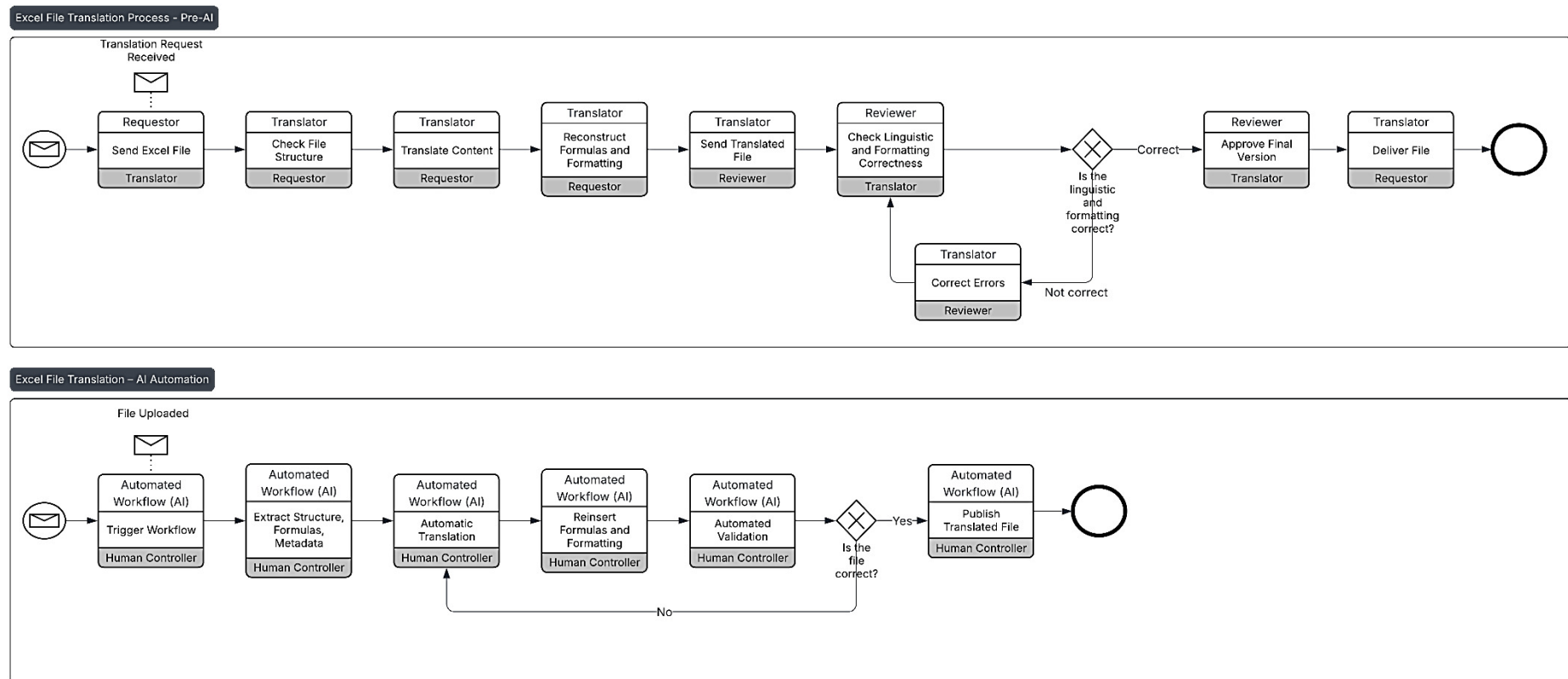
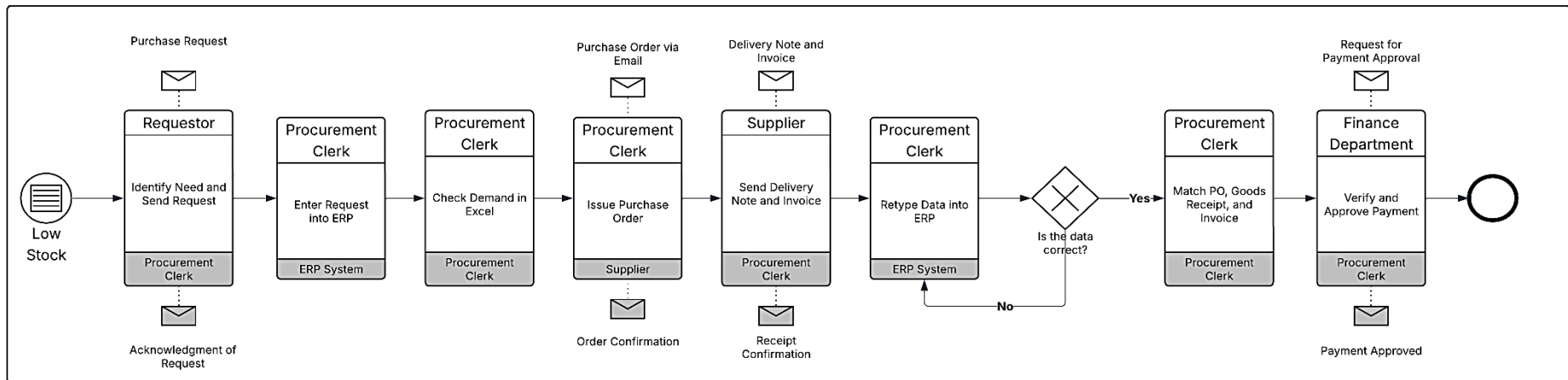


Figure 1. BPMN model of supporting business process A before and after AI implementation.

Source: own elaboration.

Procurement Process – Before AI



Procurement Process – After AI Automation

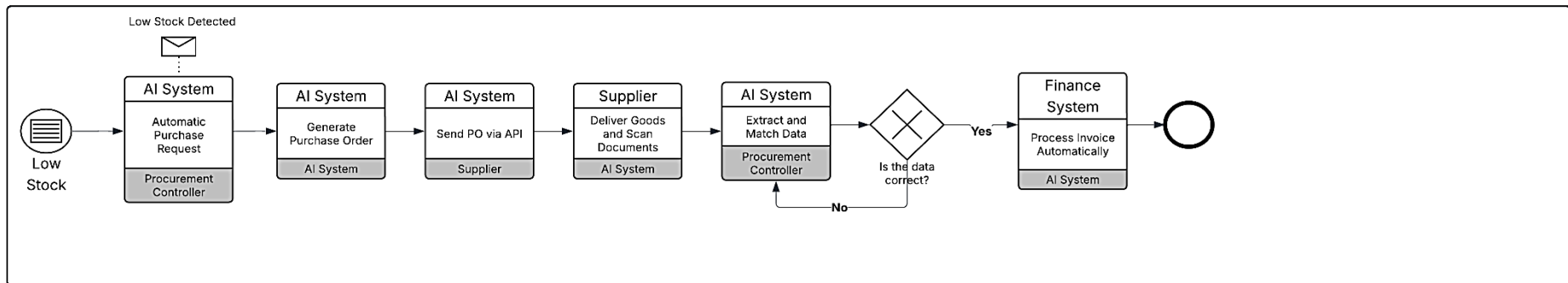


Figure 2. BPMN model of supporting business process B before and after AI implementation.

Source: own elaboration.

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