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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: economics; fintech; Artificial intelligence implementation in management; innovation management; Generation Z; ESG; tourist management; knowledge management; logistics; supply chain management; social responsibility; marketing; public management and quality management.

Radosław Wolniak

ECONOMIC ASPECTS OF THE FUNCTIONING OF SOCIAL WELFARE HOMES IN POLAND

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Purpose: Social welfare homes are one of the key elements of institutional social welfare. Their operation, and in particular the quality of the services they provide, is significantly influenced by the financial resources at their disposal. The aim of this article is to examine the economic aspects of the functioning of social welfare homes, including in particular their financing from public expenditure.

Design/methodology/approach: The article uses secondary data from the resources of the Central Statistical Office and the Ministry of Family, Labour and Social Policy. The research conducted in this article focuses primarily on the financial aspects of the functioning of social welfare homes, placing the expenditure on the functioning of these entities in the context of other public expenditure and relating it to the level of economic development of the country.

Findings: The analyses carried out showed an increase in public expenditure, both from the central budget and local government units, related to the maintenance of social welfare homes. Local governments play a particularly important role in this context, as they allocate approximately one-third of all funds earmarked for social assistance to the maintenance of social welfare homes. A significant burden here is the payment by municipalities for stays in social welfare homes – over the years, both the number of people eligible for such assistance and the average amount of such benefits granted have been increasing, which may pose a serious challenge to the entire system of financing social welfare homes in the future.

Research limitations/implications: The main limitation is the use of aggregated secondary data only, which in a way forces the use of generalizations and treats social welfare homes as a homogeneous category. However, even so, the analyses of public expenditure on the functioning of social welfare homes are noteworthy.

Originality/value: Most studies on social welfare homes focus primarily on the social or legal aspects of their operation. This study approaches the subject differently, focusing on public expenditure related to the operation of such facilities. This approach makes a significant contribution to the literature on the subject, expanding it to include aspects related to the financial burden on public budgets associated with the need to ensure the functioning of this form of social assistance.

Keywords: social assistance, social welfare home, public expenditure.

Category of the paper: research paper.

1. Introduction

In today's world, one of the important tasks of a state that cares about the welfare of its citizens is to provide assistance to people who are dependent, vulnerable and struggling with various life problems. This task is carried out through social assistance mechanisms and tools that support those who are unable to cope with difficult life situations on their own. This assistance can take various forms, from financial support, through material support, to providing care. Social welfare homes, i.e. facilities providing support and care to elderly and dependent people, play a very important role in this system. However, their operation involves significant costs, as residents must be provided not only with accommodation and food, but also with professional care, medication and other basic necessities.

In Poland, social welfare homes do not have a good image (Jurek, 2012), and their numerous shortcomings are often highlighted (Zawada, 2024), with one of the reasons for this being the insufficient financial resources available to these institutions. The results of an audit carried out by the Supreme Audit Office in 2025 also pointed to many problems in the operation of social welfare homes. A significant part of these problems concerns insufficient or incorrectly allocated funding (NIK, 2025).

The aim of this article is to examine the economic aspects of the functioning of social welfare homes, including in particular their financing from public expenditure. The functioning of social welfare, including in particular social welfare homes, is analysed in the literature on the subject primarily from a legal perspective (Szłuz, 2020; Stopka, 2021; Sierpowska, 2024) and organisational (Grabusińska, 2013; Stolińska-Poborska, 2014; Michalak, 2017; Mitreğa, 2018; Budnik, 2020) and social (Szarota, 1998; Łojko, 2014; Łuszczynska, 2018), little attention has been paid to issues related to public expenditure incurred to maintain these facilities. This article therefore fills an existing research gap.

2. The social assistance system in Poland

The understanding of social assistance has changed over time; the concept itself only appeared at the beginning of the 20th century, but social assistance itself stems from centuries-old traditions of private charity, in particular that carried out by the Church (Nitecki, 2008). The institutionalised social assistance system run by the Polish state was established by the Act of 16 August 1923 on social welfare. According to its provisions, social welfare became the state's obligation towards all those who needed such assistance (Chaczko, 2016). In the following years and under different political systems, the assumptions of the system changed quite significantly (Sierpowska, 2008). Currently, the organisation of the social

assistance system and its tasks are regulated by the Act of 12 March 2004 on social assistance (Journal of Laws 2004 No. 64, item 593). The most recent legal act that significantly changes the institutional foundations of social assistance is the Act on the provision of social services by social service centres of 19 July 2019 (Gagacka, 2022).

Social assistance is defined in many different ways in literature and practice. According to the Social Welfare Act of 12 March 2004, it is "an institution of state social policy aimed at enabling individuals and families to overcome difficult life situations which they are unable to overcome using their own rights, resources and capabilities" (Journal of Laws 2004, No. 64, item 593, art. 2.1). In turn, the definition proposed by the United Nations indicates that social assistance is "a set of factors that help individuals, families, groups and communities overcome difficult social situations caused by ongoing changes" (Lustig, Mitreęa, Stępień-Lampa, 2018, p. 54). Łojko (2022, p. 129), on the other hand, believes that "social assistance is part of the state's social policy and, at the same time, the last link in the state's social policy, established to provide assistance to individuals and families who find themselves in difficult life situations that they are unable to overcome using their own resources". Dobkowski (2009, p. 167), in turn, points out that "social assistance is most often equated with cash benefits, benefits in kind and services – not of a universal nature —provided by various entities (primarily public ones) to people who find themselves in need and are unable to satisfy their basic needs on their own or with the support of their loved ones". Kaźmierczak presents a slightly different approach to this issue, pointing to the possibility of defining social assistance in a narrow and broad sense. In the narrow sense, it will constitute a catalogue of various goods provided by relevant organisations (mainly public) to those who need help because they find themselves in a difficult life situation. In a broad sense, however, social assistance is one of the basic social institutions that plays an important role in maintaining order and integration in the social system (Bozacka, 2022).

The primary goal and task of social assistance is to support individuals and families in their efforts to meet their basic needs and enable them to live in conditions that respect human dignity. In addition, the goals of social assistance can also be considered to include the independence of individuals and families, prevention through the avoidance of difficult life situations, strengthening the family, and the integration of beneficiaries into the community (Lustig, Mitreęa, Stępień-Lampa, 2018).

When characterising social assistance, two important features can also be pointed out. Firstly, social assistance is subsidiary in nature, which means that it is intended to support beneficiaries in meeting their basic needs, rather than completely replacing them. It should therefore only be provided when an individual is unable to cope on their own (Łojko, 2022). Secondly, its tasks are carried out through the cooperation of various public administration entities, social and non-governmental organisations, churches and religious associations, as well as natural and legal person (Nitecki, 2008; Lustig, Mitreęa, Stępień-Lampa, 2018).

The literature on the subject also indicates that the social assistance system performs several basic functions, which are (Kubów, 2010):

- Diagnostic function: concerns the identification of social needs and phenomena in a given environment.
- Social security function: concerns ensuring a decent existence for citizens.
- Rescue function: implemented through financial and non-financial support for people who, due to difficult life experiences, do not have a secure existence.
- Social education function: concerns the promotion of activities related to social assistance and the development of attitudes of shared responsibility for oneself and others.
- Socialisation function: concerns increasing social activity in the implementation of measures aimed at overcoming difficulties; such measures may include, for example, volunteering and participation in charitable activities.

The primary task of social assistance is to provide benefits. Social benefits are "all funds, material goods and services that serve to satisfy the individual needs of individuals and families, obtained without equivalent value, i.e. not constituting remuneration for work financed from public funds" (Lustig, Mitręga, Stępień-Lampa, 2018). Article 36 of the Social Assistance Act indicates that these benefits can be divided into two basic groups: cash benefits and non-cash benefits (Journal of Laws 2004, No. 64, item 593). Cash benefits include allowances and loans, cash benefits for foreigners who meet certain conditions, as well as remuneration due to a carer for providing care, awarded by a court (Adamowicz, Borczyńska, 2016). Non-cash benefits include both benefits in kind and services in the form of community or institutional assistance (Szweda-Lewandowska, 2017).

The structure of the social assistance system in Poland currently consists of two main elements: government administration and local government institutions. Their task is to provide social assistance, which is carried out by bodies located at various organisational levels. Within the government administration, the most important bodies are the ministry responsible for social security (currently the Ministry of Family, Labour and Social Policy) and the social policy departments established at provincial offices. At the local government level, these tasks are carried out by regional social assistance centres established at marshal's offices, district social assistance centres and family assistance centres, as well as social assistance centres (at the municipal level) (Bozacka, 2022). The social assistance system also includes many specialised entities providing specific types of support. These are primarily social welfare homes, support centres, crisis intervention centres and specialist counselling centres (Kaczmarek, 2014).

The delegation of social assistance tasks to local government units is justified by two principles: subsidiarity and subsidiary. It is the smallest administrative unit, closest to the community, that has the best chance of correctly identifying needs and emerging problems and responding to them effectively. Therefore, it is the municipalities that are responsible for

implementing the widest range of social assistance tasks. Tasks that exceed the capabilities of municipalities are to be carried out by counties. Control over the functioning of social assistance is exercised by voivodes as representatives of the Council of Ministers in the field. They issue and revoke permits to operate social assistance facilities and control the quality of services provided by them (Sierpowska, 2008).

3. Social welfare homes as a key element of the social assistance system

The activities of social welfare homes are primarily regulated by two legal acts: the Social Welfare Act of 12 March 2004 (Journal of Laws 2004 No. 64, item 593) and the Regulation of the Minister of Labour and Social Policy of 23 August 2012 on social welfare homes (Journal of Laws of 2012, item 964). As indicated in Article 54 of the Social Welfare Act, "a person requiring round-the-clock care due to age, illness or disability, unable to function independently in everyday life, who cannot be provided with the necessary assistance in the form of care services, has the right to be placed in a social welfare home" (Journal of Laws 2004 No. 64, item 593, art. 54). A social welfare home (SWH) can be defined as "a traditional form of institutional social assistance in the form of round-the-clock or day care for people unable to live independently, who cannot be fully adapted to independent living in their place of residence due to their age, medical condition, life situation and family, housing and material conditions, despite the use of all forms of assistance" (Mitręga, 2018, p. 598).

In accordance with the provisions of the Social Welfare Act, a social welfare home is obliged to provide its residents with living, care, support and educational services at the applicable standard, taking into account their individual needs. This is to be done while taking into account the freedom, privacy, dignity and sense of security of the residents and their level of physical and mental fitness (Journal of Laws 2004, No. 64, item 593). Living needs are met by providing accommodation, food, clothing, footwear and cleanliness. Care services include assistance with basic activities of daily living, personal matters and nursing care. Support services include social activation, facilitating contact with family, enabling participation in occupational therapy, satisfying religious and cultural needs, and activities aimed at helping residents become independent (Michalak, 2018).

Social welfare homes are very diverse, and individual facilities may be targeted at specific categories of people in need. Article 56 of the Social Welfare Act specifies the following types of social welfare homes (Journal of Laws 2004, No. 64, item 593):

- For the elderly.
- For people with chronic somatic illnesses.
- For people with chronic mental illness.
- For adults with intellectual disabilities.

- For children and young people with intellectual disabilities.
- For physically disabled people.
- For people addicted to alcohol.

However, according to the provisions of the Act, it is possible to combine different types of social welfare homes in the following configurations: elderly people with people suffering from chronic somatic illnesses; people suffering from chronic somatic illnesses with physically disabled people; elderly people with physically disabled people; intellectually disabled adults with intellectually disabled children and young people (Łuszczynska, 2018).

A specific group of entities is authorised to run social welfare homes, namely: local government units, the Catholic Church, other churches, religious associations and social organisations, foundations and associations, other legal person and natural person (Klepacki, 2018). However, in order to run such a home, it is necessary to obtain the consent of the voivode competent for the location of the facility. The voivode issues a permit for an indefinite period to facilities that meet all the requirements and standards specified in the law and enters the facility in the register of social welfare homes kept by him. This register is public and updated on an ongoing basis (Journal of Laws 2004, No. 64, item 593).

Although placement in a social welfare home requires an administrative decision by the local authority, the stay in the facility is not free of charge. The fee for the stay is currently set at the level of the average monthly cost of living – this cost is determined by the local authorities responsible for the given social welfare home and published in the provincial official journal (Journal of Laws 2004, No. 64, item 593). In the case of people placed in a social welfare home after 1 January 2004, the resident of the social welfare home is obliged to pay the fees in the first instance (however, this cannot exceed 70% of their income), followed by their family members (spouse, descendants, ascendants), and if the family does not have sufficient financial resources, the municipality is obliged to cover the shortfall (Iwański, Szafranek, 2024). However, payment for the stay of residents admitted before that date is made according to the "old rules", which means that the issues related to payment are slightly different. In this case, there is no obligation to pay imposed on the family members of the resident (the resident himself pays up to 70% of his income), but there is a specific subsidy from the state budget (NIK, 2025). Such double rules for financing social welfare homes greatly complicate their functioning.

4. Methods

This article is based on data from several sources. The first of these are reports on social assistance statistics published annually by the Ministry of Family, Labour and Social Policy. Reports from 2015-2024 were analysed. The second source is studies by the Central Statistical

Office on the functioning of residential social assistance facilities, also covering the years 2015-2024. Data on Poland's GDP and inflation rate also come from the Central Statistical Office.

The data obtained in this way was subjected to descriptive analysis and basic statistical analysis. Changes in public expenditure related to the functioning of social welfare homes were presented and analysed, and a spatial analysis of these expenditures was also carried out. Expenditures incurred for the maintenance of these facilities were also linked to GDP. Table 1 presents basic data characterising social welfare homes in the period under study.

Table 1.

Basic characteristics of social welfare homes in 2015-2024 (as at 31 December each year)

Year	Number of facilities	Number of places	Number of residents	Occupancy rate at the end of the year (%)	Residents in the reporting year	Number of employees
2015	853	80,759	79,300	98.19	n/d	54,531
2016	863	81,465	80,095	98.32	n/d	55,061
2017	859	81,242	80,436	99.01	n/d	54,469
2018	876	82,801	81,912	98.93	n/d	55,839
2019	875	82,840	81,795	98.74	95,423	54,909
2020	871	82,660	77,060	93.23	93,099	56,194
2021	897	84,200	79,919	94.92	93,282	56,121
2022	902	84,617	80,604	95.26	95,215	56,157
2023	904	84,584	81,570	96.44	96,441	56,863
2024	903	84,319	82,077	97.34	97,243	57,486

Source: own study based on data from the Central Statistical Office and the Ministry of Family, Labour and Social Policy.

The number of social welfare homes operating in Poland is generally on the rise (it increased by 50 in the analysed period), but slight fluctuations can be observed in some years. The largest increase in the number of facilities was recorded in 2021, which is quite an interesting phenomenon in the context of the COVID-19 pandemic that was ongoing at the time. The situation is similar in the case of the number of places (which seems natural), although slight decreases can be seen in the last three years, but on this basis it is still difficult to judge a more permanent downward trend. In the case of the number of residents, a significant decrease can be seen in 2020, which is obviously related to the most difficult stage of the COVID-19 pandemic. On the one hand, it caused many deaths among residents, and on the other, it significantly hampered and slowed down the admission of new residents (as presented in more detail in Table 2). This is confirmed by data on the total number of residents in the reporting year, which in 2020 was significantly lower than in the previous year. This number returned to its pre-pandemic level in 2022.

It is also worth noting that in all the years analysed, the occupancy rate of the homes was less than 100% at the end of the year. It was lowest during the pandemic, which is understandable, but since 2020, when the largest decline occurred, the occupancy rate of social welfare homes has been steadily increasing. The analysis of the occupancy rate of social welfare homes is important because the lower it is, the greater the financial problems of these units, which often calculate unit costs for the maximum number of residents. The pandemic period

was therefore particularly difficult in financial terms: on the one hand, lower occupancy, on the other, higher costs associated with the need to ensure increased security.

The number of social welfare home employees increased during the analysed period, but the rate of this increase was proportionally slightly lower than in the case of the number of facilities. The data indicate that after a fairly significant decline in the number of employees in social welfare homes in 2019, their number increased significantly in the first year of the pandemic, and this increase, although not as dynamic, continues. Interestingly, however, in 2021, the relatively large increase in the number of social welfare homes (and the number of places available in them) was not accompanied by an equally large increase in the number of employees – in fact, this number decreased.

Table 2.

Changes in the number of residents in social welfare homes in 2015-2024

Year	Admissions during the reporting year	Left during the reporting year	
		Total	The deceased
2015	11,796	11,397	9,585
2016	11,802	11,115	9,370
2017	12,543	12,071	10,195
2018	12,734	12,374	10,556
2019	12,633	12,615	10,681
2020	10,696	15,320	13,637
2021	13,694	11,890	9,999
2022	12,783	12,223	10,252
2023	13,387	12,403	10,275
2024	14,732	13,663	10,239

Source: own study based on data from the Ministry of Family, Labour and Social Policy.

The data in Table 2 confirm the earlier conclusions regarding the impact of the COVID-19 pandemic on changes in the number of residents in social welfare homes. They clearly indicate that in 2020 there was a significant decrease in the number of people admitted to social welfare homes, which was undoubtedly the result of restrictions introduced in connection with the pandemic. 2020 was also the only year in which the number of admissions was lower than the number of residents who left. What is more, more residents of social welfare homes died than were admitted to these facilities in that year. Death is the most common reason for a resident leaving a social welfare home, and 2020 was a record year in this sense. In subsequent years, these numbers returned to pre-pandemic norms, clearly indicating that the pandemic was a tremendous shock to the entire system.

5. Results and Discussion

Social welfare homes throughout Poland operate on the same principles, but their functioning and number are greatly influenced by regional conditions (Table 3).

Table 3.*Social welfare homes in the voivodships in 2024 (as of 31 December)*

Voivodship	Number of facilities	Number of places	Number of places per 1,000 inhabitants	Local government expenditure (PLN thousand)	Average expenditure per facility (PLN thousand)	Average expenditure per place (PLN thousand)
Dolnośląskie	68	6,129	2.14	695,965	10,234.8	113.6
Kujawsko-Pomorskie	49	4,127	2.08	528,628	10,788.3	128.1
Lubelskie	45	4,467	2.24	448,620	9,969.3	100.4
Lubuskie	23	2,234	2.30	315,142	13,701.8	141.1
Łódzkie	68	6,630	2.83	579,882	8,527.7	87.5
Małopolskie	94	8,220	2.40	856,762	9,114.5	104.2
Mazowieckie	107	9,936	1.80	1,053,827	9,848.9	106.1
Opolskie	29	3,048	3.28	284,111	9,796.9	93.2
Podkarpackie	54	4,942	2.40	456,909	8,461.3	92.5
Podlaskie	22	2,361	2.08	261,206	11,873.0	110.6
Pomorskie	45	4,385	1.86	489,065	10,868.1	111.5
Śląskie	102	8,991	2.10	840,286	8,238.1	93.5
Świętokrzyskie	42	3,898	3.37	365,956	8,713.2	93.9
Warmińsko-mazurskie	49	4,119	3.05	388,021	7,918.8	94.2
Wielkopolskie	68	6,527	1.88	767,657	11,289.1	117.6
Zachodniopomorskie	38	4,305	2.65	453,666	11,938.6	105.4
POLAND	903	84,319	2.25	8,785,703	9,729.5	104.2
Maximum	107	9,936	3.37	1,053,827	13,701.80	141.1
Minimum	22	2,234	1.80	261,206	7,918.80	87.5
Median	49	4,426	2.27	472,987	9,909.10	104.8
Mean	56.44	5,269.94	2.40	549,106.44	10,080.15	105.84
Standard deviation	25.53	2,209.14	0.48	224,099.81	1,549.89	13.98

Source: own study based on data from the Central Statistical Office and the Ministry of Family, Labour and Social Policy.

In 2024, there were 903 social welfare homes operating in Poland. The highest number was in the Mazowieckie and Śląskie Voivodships (over 100), while the lowest was in the Lubuskie and Podlaskie Voivodships (less than 25). The situation was similar in terms of the number of places available in these facilities. However, when looking at the number of places per 1000 inhabitants, the situation is slightly different. The highest number was in the Opolskie, Świętokrzyskie and Warmińsko-Mazurskie Voivodships (over 3 places per 1000 inhabitants), while the lowest was in the Mazowieckie, Pomorskie and Wielkopolskie Voivodships (less than 2 places per 1000 inhabitants). This indicates that in the Mazowieckie Voivodship, despite having the largest number of social welfare homes in Poland, their availability per capita is one of the lowest, which is obviously due to the large number of inhabitants. It should be emphasised here that the availability of places in social welfare homes throughout Poland is relatively low.

An analysis of local government expenditure on the operation of social welfare homes in individual voivodships also provides interesting conclusions. As might be expected, the highest expenditure was in the Mazowieckie Voivodship, where the largest number of these facilities operated, and the lowest in the Podlaskie Voivodship, where there were the fewest facilities.

However, the second highest expenditure was recorded in the Małopolskie Voivodship, although there were more social welfare homes in the Śląskie Voivodship. The situation is similar at the other end of the scale – the second lowest expenditure was incurred by the Opolskie Voivodship, although it had more facilities than the Lubuskie Voivodship. This clearly indicates that local government expenditure varies from region to region and is not directly proportional to the number of facilities.

An analysis of average local government expenditure per facility also confirms significant differences between voivodships, although in this case it should be remembered that individual social welfare homes also differ in the number of places they offer. By far the highest average expenditure per facility is in the Lubuskie Voivodship, which is almost PLN 2 million higher than in the next highest voivodship (which is the Zachodniopomorskie Voivodship). The lowest average expenditure per facility is incurred by local governments in the Warmińsko-Mazurskie Voivodship. The difference between the voivodships with the highest and lowest average local government expenditure per facility (Lubuskie and Warmińsko-Mazurskie Voivodships) is almost PLN 5.8 million. The situation is different in the case of average expenditure per place. It is by far the highest in the Lubuskie Voivodship, slightly lower in the Kujawsko-Pomorskie Voivodship, and the lowest in the Łódzkie Voivodship.

The differences in all the categories analysed should be considered significant, as confirmed by the statistical values presented in Table 3. They indicate large differences between the maximum and minimum values, significant discrepancies in the median and average values, and relatively high standard deviation values. While the several-fold difference in the number of facilities and places (as well as, to some extent, the amount of local government expenditure) between voivodships can be explained by the difference in the number of inhabitants in these regions, there is no such easy explanation for the other categories. They cannot be fully explained by differences in prices and living costs, although this is obviously one of the differentiating factors. The need for municipalities to cover part of the fees for people staying in social welfare homes, as well as the type and standard of individual facilities and the associated relatively high average cost of maintenance, certainly have a significant impact. However, such large regional disparities raise the question of how they can be reduced, especially in the case of average expenditure per place. It is assumed that social welfare homes are one of the more expensive forms of institutional care, so, especially in the case of several provinces with the highest expenditure, it is worth considering providing people in need with other forms of assistance, such as community self-help homes or much cheaper community care provided in their places of residence. It may also be necessary to reorganise the facilities operating in these areas in order to optimise their costs.

The expenditure incurred by local government units is not the only public expenditure related to the functioning of social welfare homes. State budget expenditure also plays an important role, for example in the form of targeted subsidies for the maintenance of residents

staying in social welfare homes under the so-called "old rules". Table 4 presents data on expenditure from both the state budget and local government units in the years 2015-2024.

Table 4.

Public expenditure related to the functioning of social welfare homes in Poland in 2015-2024

Year	State budget expenditure on social welfare homes			Local government expenditure on social welfare homes			Public expenditure on social welfare homes as a percentage of GDP
	thousand PLN	as a % of social assistance expenditure	as a % of total expenditure	thousand PLN	as a % of social assistance expenditure	as a % of total expenditure	
2015	843,401	5.74	0.2542	3,473,033	13.99	1.7682	0.2398
2016	870,413	2.54	0.2412	3,707,732	8.30	1.7996	0.2457
2017	892,983	18.98	0.2376	4,033,763	30.37	1.7525	0.2476
2018	906,872	19.82	0.2353	4,403,256	31.48	1.6976	0.2497
2019	930,029	20.04	0.2245	4,823,678	32.53	1.7215	0.2514
2020	986,492	21.09	0.1954	5,361,002	33.97	1.7915	0.2686
2021	889,822	19.42	0.1733	5,577,057	34.15	1.7651	0.2430
2022	875,418	11.78	0.1692	6,163,505	25.94	1.7418	0.2270
2023	1,221,040	22.76	0.1852	7,459,746	34.78	1.9378	0.2542
2024	1,246,388	14.57	0.1494	8,785,703	32.77	2.0326	0.2746

Source: own study based on data from the Central Statistical Office and the Ministry of Family, Labour and Social Policy.

Over the 10 years analysed, both state budget expenditure and local government expenditure incurred in connection with the operation of social welfare homes increased significantly (in the case of local government expenditure, this represents an increase of more than twofold). Local government expenditure showed an upward trend throughout the period, while in the case of central government expenditure, this trend reversed in 2021-2022, but already in 2023 there was a sharp increase in funds allocated to social welfare homes. However, it is much more interesting to analyse the size of these expenditures as a percentage of total social assistance expenditures, total budget expenditures and GDP. Any discussion of the share of social welfare home expenditure in total state and local government social assistance expenditure should be preceded by the information that, up to and including 2016, the "social assistance" section included expenditure on care and educational facilities, the "500 plus" child benefit (which began operating in 2016), family benefits, maintenance fund benefits, social security pension and disability insurance contributions, and expenditure on foster families. This explains the huge discrepancies in 2015-2016 compared to the rest of the period analysed. In other years, state budget expenditure on social welfare homes fluctuated around 20% of total social assistance expenditure. This shows that the costs associated with the operation of social welfare homes are a significant element from the point of view of the financial capabilities of the entire system. Expenditure on this type of activity is even more significant in local government budgets, where it accounts for approximately one-third of social assistance expenditure. The exception was 2022, when this share fell to approximately 25%, but this was due to a significant increase in other expenditure rather than a decrease in expenditure on social welfare homes.

When analysing data on the share of expenditure on social welfare homes in the total expenditure of the state budget and local government units, it can be seen that it is significantly more important in the latter case. Moreover, despite some fluctuations, this share increased by approximately 0.25 percentage points between 2015 and 2024, mainly due to a significant increase recorded in 2023-2024. For the state budget, expenditure on social welfare homes is of rather marginal importance, which is also constantly decreasing (with the exception of 2023, which was also a record year in terms of the share of expenditure on social welfare homes in total social welfare expenditure). This clearly shows that the growth in expenditure related to the functioning of social welfare homes is characterised by a much lower rate than the growth in other budgetary expenditure. The picture of expenditure on social welfare homes against one of the basic macroeconomic indicators, gross domestic product, is also interesting. The data presented in Table 3 show that, despite relatively significant fluctuations in individual years, these expenditures increased more than Poland's GDP over the analysed period (these expenditures, measured as a percentage of GDP, were higher in 2024 than in 2015). This indicator reached its lowest value in 2022, which was due to a decrease in state budget expenditure on this task and (above all) to the very high growth in GDP in that year. However, this does not change the fact that, given the size of GDP, public expenditure on social welfare homes is becoming an increasingly important (though still marginal) category.

Analyses of public expenditure on the operation of social welfare homes cannot be considered complete without examining how this expenditure has changed over time in terms of per facility and per resident. These data are presented in Table 5.

Table 5.

Public expenditure on social welfare homes per facility and per resident

Year	Average expenditure per facility	Average expenditure per resident	Dynamics of average expenditure per facility (previous year = 100)	Dynamics of average expenditure per resident (previous year = 100)	Base price index (previous year = 100)
2015	5,335,443.14	57,391.34	-	-	-
2016	5,304,918.89	57,158.94	99.43	99.60	99.4
2017	5,735,443.54	61,250.51	108.12	107.16	102.0
2018	6,061,789.95	64,827.23	105.69	105.84	101.6
2019	6,575,665.14	70,343.02	108.48	108.51	102.3
2020	7,287,593.57	82,370.80	110.83	117.10	103.4
2021	7,209,452.62	80,917.92	98.93	98.24	105.1
2022	7,803,684.04	87,327.22	108.24	107.92	114.4
2023	9,602,639.38	106,421.30	123.05	121.86	111.4
2024	11,109,735.30	122,227.80	115.69	114.85	103.6

Source: own study based on data from the Central Statistical Office and the Ministry of Family, Labour and Social Policy.

2016 and 2021 were the only years in which average expenditure per facility and per resident was lower than in the previous year, which, especially in the case of 2021, was due to the large number of newly established facilities (and, consequently, a larger number of residents). In this case, it can be said that public expenditure did not keep pace with the growth

of the sector. In other years, this expenditure increased, with a particularly large increase observed in 2023-2024. Throughout the analysed period, these expenditures (both per facility and per resident) more than doubled, which was naturally influenced by inflation. However, the data in the table clearly show that the growth rate of average public expenditures on social welfare homes was higher than inflation (except for 2021-2022), which on the one hand may be positive in the context of the functioning of these entities, but may also mean that the state, and especially local government units, must (contrary to the statutory assumptions) bear an increasing financial burden for the operation of this form of social assistance. The highest growth rate in average expenditure per facility was recorded in 2023, while the highest growth rate per capita was recorded in 2022. However, when the impact of inflation is excluded, the situation looks slightly different: the highest growth rate in expenditure per facility was recorded in 2024, and the highest growth rate per capita was recorded in 2020.

One of the reasons for the increase in local government expenditure is the need for municipalities to pay fees for residents of social welfare homes who are unable to cover the costs of their stay in a social welfare home themselves (even with the help of their families). Table 6 presents data on municipal payments for stays in social welfare homes in 2015-2024.

Table 6.

Municipal payments for stays in social welfare homes in 2015-2024

Year	Number of people granted the benefit	Number of benefits granted	Amount of benefits in PLN	Average amount of benefits in PLN
2015	50,293	498,242	1,094,765,522	2,197.26
2016	55,872	557,436	1,253,184,354	2,248.12
2017	59,355	589,598	1,419,580,625	2,407.71
2018	61,917	626,231	1,553,782,087	2,481.16
2019	63,915	657,556	1,731,820,504	2,633.72
2020	63,858	649,672	1,790,823,003	2,756.50
2021	64,170	654,866	1,980,574,969	3,024.40
2022	65,615	678,209	2,237,320,910	3,298.87
2023	68,057	696,978	3,022,630,996	4,336.77
2024	70,023	724,246	3,268,371,974	4,512.79

Source: own study based on data from the Central Statistical Office and the Ministry of Family, Labour and Social Policy.

The amount of benefits related to municipal payments increased almost threefold between 2015 and 2024, with the highest increase recorded in 2023 – it reached 35% compared to the previous year. The increase in local government expenditure is largely due to a significant increase in the number of beneficiaries who have been granted benefits consisting of municipal payments for their stay in social welfare homes. Over a period of 10 years, their number has increased by almost 20,000 people, which represents an increase of almost 40%. This has resulted in the number of benefits granted increasing by approximately 45%. However, this is not the only reason – the second, and perhaps even more important, reason is the fact that the average amount of the benefit has increased significantly. This, in turn, is due to increases in the average cost of living for a social welfare home resident – an increase that cannot usually

be covered by the residents themselves or their families, so municipalities have to pay more and more for their stay. The average amount of benefits more than doubled during the period analysed. This clearly indicates an increasing burden on municipalities in this category of expenditure, which may lead to even greater inefficiency of the entire system in the future.

6. Summary

Social welfare homes are an indispensable element of the Polish social welfare system, providing care for dependent people who cannot be helped in any other way. According to the assumptions of the act, their financing was to be shared between the state and the beneficiaries themselves (or their families). In reality, however, a significant part (and sometimes even the entirety) of the costs associated with maintaining individual residents of social welfare homes must be covered by public authorities. As a result, expenditure on this task is constantly growing and, although it represents a small fraction of total public expenditure, its importance in local government budgets has been increasing in recent years. Given the steadily increasing number of beneficiaries whose stay in social welfare homes is co-financed by municipalities and the increase in the average amount of such benefits, it can be assumed that this trend is likely to continue. At the same time, however, the availability of places in social welfare homes is insufficient and varies greatly from region to region. Significant budgetary constraints on local governments mean that a rapid increase in the number of these facilities and the places available in them is unlikely in the coming years.

Chronic underfunding of social welfare homes results in a decline in the quality of services provided, staff shortages (with inadequate remuneration) and many other problems. It should therefore come as no surprise that these institutions do not enjoy a good reputation among the public. However, changing their image requires significant investment and reorganisation of the entire financing system in order to optimise costs and ensure more even participation, or a significant increase in state involvement in financing these units. However, given the size of the budget deficit and public debt, and bearing in mind that public spending is currently focused on other areas, it is unlikely that there will be any significant increase in state involvement.

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LANDSCAPE OF FINTECH AND TRUST RESEARCH: PARTNERSHIP NETWORKS AND THEMATIC EVOLUTION

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Purpose: The purpose of this study is to map and assess the development of academic research on the relationship between fintech and trust between 2016 to 2024. It aims to identify the most active countries, institutions, and sources of publications, analyze collaboration networks, and uncover emerging thematic areas that define interdisciplinary field.

Design/methodology/approach: Through a bibliometric approach based on Scopus and Web of Science data, the study explores how research productivity, partnership networks, and conceptual focuses have evolved over research period, identifies publication trends.

Findings: The analysis reveals a dynamic and growing interest in the topic of fintech and trust, with publications increasing from a single paper in 2016 to over 120 in 2024. The results show that China, India and Malaysia are leading contributors, although countries such as the UK and the USA demonstrate stronger international collaboration. Two main models of research activity are observed: nationally focused hubs (e.g. China, India) and intentionality connected networks (e.g. UK, USA, Malaysia).

Research limitations/implications: Dataset covers the period 2016-2024 more recent publications or ongoing research trends might not yet be fully visible. Future research should build: comparative cross-cultural analyses, with describing differentiation in the perspective rules and cultural environments. Exploration of emerging technologies, and their influence on trust formation and risk perception.

Originality/value: The research provides comprehensive bibliometric overviews of the fintech and trust literature, offering a structured view of how the field has evolved and where research gaps remain. By using bibliometric approach is reveal not only who leads this research area, but also how international cooperation and thematic directions have evolved from 2016 to 2024. The findings add value by clarifying the structure of this research domain and emphasizing the central role trust in sustainable digital finance development.

Keywords: fintech, customer behavior, trust, bibliometric analysis.

Category of the paper: Research paper.

1. Introduction

The issue fintech and trust is important because it addresses one of the most dynamic and transformative areas in modern finance. The rise of financial technologies (fintech) has revolutionized how financial services are delivered, creating new business models, reshaping consumer behavior, and challenging traditional institutions. However, this rapid technological advancement also raises critical questions about trust, which is fundamental element for relation in the financial market. Research clearly indicates that customer trust is one of the most important factors influencing the willingness to use fintech services. Trust surpasses other aspects such as easy of use or innovation, and directly translates into both the intention to use and actual usage of these services (Zhao et al., 2024; Amnas et al., 2023; Roh et al., 2024; Rhanoui, 2022; Hu et al., 2019). A lack of trust, stemming, for example, from concerns about data security, technical failures, or unclear policies, effectively discourages customers from adopting fintech solutions (Jafri et al., 2023; Chawla et al., 2023).

Among the main factors contributing to building trust, the following were mentioned. Data security and privacy. Users expect robust safeguards, clear privacy policies, and transparent communication regarding data protection (Zhang et al., 2023; Adelaja et al., 2024; Chawla et al., 2023). The next factor was reputation and regulatory compliance. Platforms perceived as trustworthy, compliant with regulations, and committed to consumer protection foster greater trust (Adelaja et al., 2024; Chawla et al., 2023). Additionally, important factors included the quality of customers service and support, such as prompt responses to issues, personalized communication, and the experiences shared by other users (Rhanoui, 2022; Chawla et al., 2023, Czechowska et al., 2024).

Considering the social significance and importance of the topic research studies connected acting fintech with clients trust identity which areas are most developed, and where research gaps remain. By examining potential partnership networks, it possible to see how countries, institutions, and research collaborate, revealing the global nature of financial innovation and knowledge exchange. The analysis of thematic evolution shows how research topics have shifted over time. From for example early studies on digital payments to current interest in blockchain, artificial intelligence, and cybersecurity (Rahman et al., 2023). This leads to insight into emerging priorities and trends. Eventually clarify how fintech and trust interact to shape modern financial ecosystems and identify the factors which foster sustainable innovation, financial inclusion, and client confidence in digital financial systems (Czechowska, Paduszyńska, 2024b). Financial sector institutions are very active in using and applying digitization technologies. The banking sector has many achievements in this area, which are related to adopting digital banking instead of traditional banking methods (Czechowska, Paduszyńska, 2024a).

The main aim of this study is to identify and assess the map of the development of academic research on fintech and trust between 2016 to 2024.

The study seeks the answer for research questions about:

1. The most active countries, institutions, and publication sources.
2. The patterns of research collaboration across regions.
3. The emerging thematic areas that have shaped this field.

To achieve these goals and answer these questions, a bibliometric analysis was used based on data extracted from the Scopus and Web of Science databases. The dataset includes peer-reviewed articles containing the keywords *fintech* and *trust*. Using bibliometric tools such as Bibliometrix (R package), the study examined publication trends, co-authorship networks, and the co-occurrence of keywords to reveal both structural relationships and conceptual dynamics within this research domain (Aria, Cuccurullo, 2017).

2. Research method

In this study, a bibliometric analysis was performed to examine research trends in fintech and trust, using data obtained from both the Scopus database and the Web of Science Core Collection (Clarivate Analytics). These are scientific databases that provide access to high-quality research materials. The bibliometricx package (*bibliometrix*, [www1](#)) developed by (Aria, Cuccurullo, 2017) and available in R software (version 4.5.1) was used, which allows the implementation of many bibliometric analysis methods. It is an open source tool.

The first stage involved searching selected scientific databases for trust and fintech. The search included titles, abstracts, and keywords assigned to research papers. The study covered scientific articles and reviews written in English. The research period was limited to the last full year, that is, 2024 (so that it would be possible to compare the results obtained with those covering subsequent years and reproduce the procedure using the same bibliographic sources). Ultimately, the research period covered the years 2016-2024. The individual stages of the research process are shown in Figure 1.

In the research process, using the *bibliometrix* tool, it is possible to implement data downloaded from the Scopus and Web of Science databases (each scientific article contains several fixed elements such as authors' names, keywords, etc.). The export file can be read and converted using R with the *convert2df* function (*bibliometrix*, [www1](#)). Using the *marge* function, it is possible to combine both sets. After removing duplicate scientific articles, a final database was obtained consisting of 453 records.

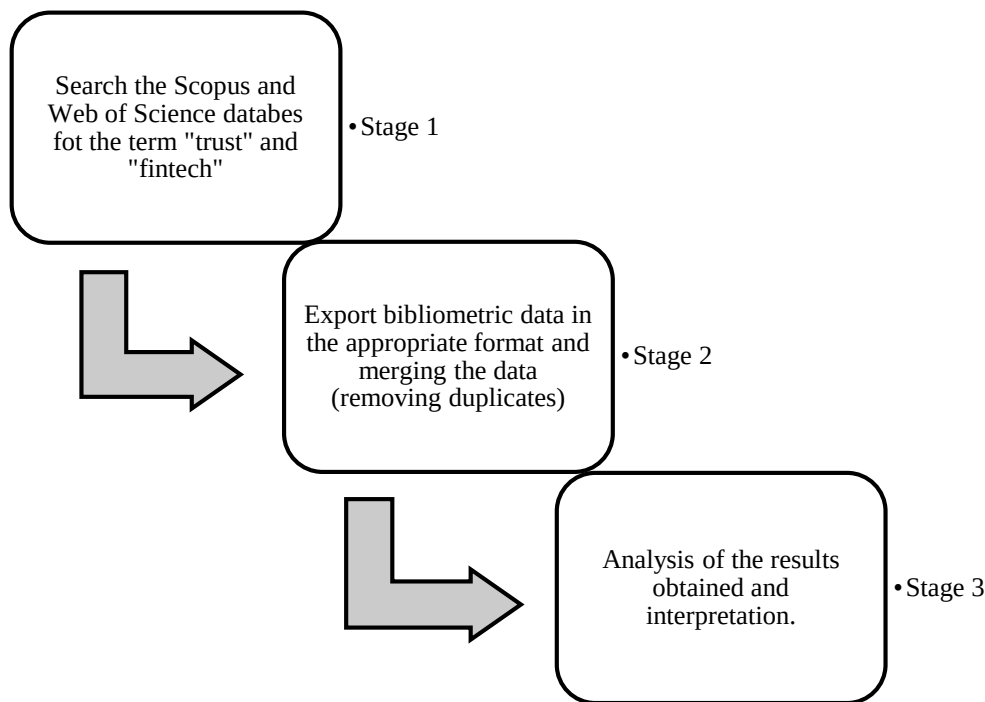


Figure 1. Stages of the bibliometric analysis.

Source: own study.

Using the *biblioAnalysis* function (*bibliometrix*, *www1*), it is possible to present descriptive statistics for the implemented bibliographic data. In turn, using the *summary* command (*bibliometrix*, *www1*), it is possible to present main information about the bibliographic data frame and several tables, such as annual scientific production, top manuscripts per number of citations, most productive authors, most productive countries, total citation per country, most relevant sources (journals), and most relevant keywords (Aria, Cuccurullo, 2017).

The results of the procedures carried out in the field of publication analysis, international cooperation between authors, and keyword co-occurrence analysis are presented in the next section.

3. Main findings

The first step of the study involved a numerical analysis of publications on fintech and trust issues between 2016 and 2024 (Figure 2).

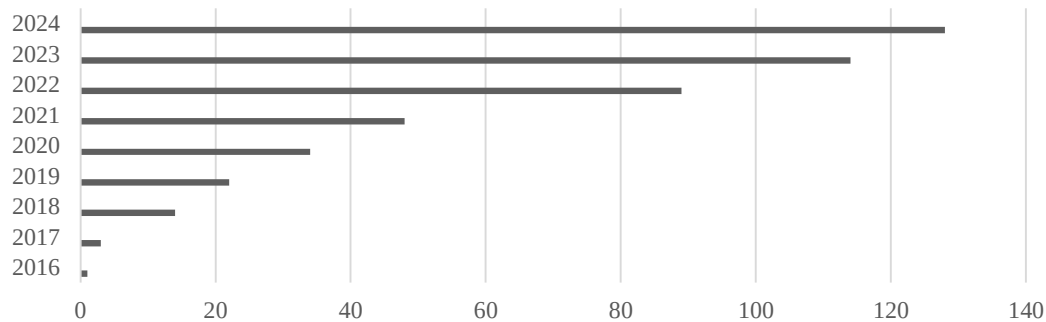


Figure 2. Number of scientific articles in the field of fintech and trust in 2016-2024.

Source: own study using the bibliometrix tool within the R software.

The results reveal a dynamic and rapidly expanding field, with the annual number of publications increasing from only one in 2016 to over 120 in 2024. The annual growth rate of publications in the studied area in the years considered was approximately 83.4%.

As part of descriptive statistics, the *biblioAnalysis* function (*bibliometrix*, *www1*) was used to present the most frequently cited scientific articles (Table 1).

Table 1.

Ten most frequently cited scientific articles in the field of trust and fintech

Author(s) (year)	Title of article and DOI number	TC	TC PER YEAR	NTC
Chen, Bellavitis (2020)	Blockchain Disruption and Decentralized Finance: The Rise of Decentralized Business Models DOI: https://doi.org/10.1016/j.jbvi.2019.e00151	493	82,2	9.25
Gai et.al. (2018)	A survey on FinTech DOI: https://doi.org/10.1016/j.jnca.2017.10.011	258	32.2	2.45
Anagnostopoulos (2018)	Fintech and Regtech: Impact on regulators and banks DOI: https://doi.org/10.1016/j.jeconbus.2018.07.003	248	31.0	2.36
Albayati et al. (2020)	Accepting financial transactions using blockchain technology and cryptocurrency: A customer perspective approach DOI: https://doi.org/10.1016/j.techsoc.2020.101320	239	39.8	4.48
Hu et al. (2019)	Adoption Intention of Fintech Services for Bank Users: An Empirical Examination with an Extended Technology Acceptance Model DOI: https://doi.org/10.3390/sym11030340	229	32.7	4.52
Jünger, Mietzner (2020)	Banking goes digital: The adoption of FinTech services by German households DOI: https://doi.org/10.1016/j.frl.2019.08.008	180	30.0	3.38
Tseng et al. (2018)	Governance on the Drug Supply Chain via Gcoin Blockchain DOI: https://doi.org/10.3390/ijerph15061055	169	21.1	1.61
Cai (2018)	Disruption of financial intermediation by FinTech: a review on crowdfunding and blockchain, DOI: https://doi.org/10.1111/acfi.12405	156	19.5	1.48
Lim et al. (2019)	An Empirical Study of the Impacts of Perceived Security and Knowledge on Continuous Intention to Use Mobile Fintech Payment Services DOI: https://doi.org/10.1080/10447318.2018.1507132	156	22.3	3.08
Arias-Oliva et al. (2019)	Variables Influencing Cryptocurrency Use: A Technology Acceptance Model in Spain, DOI: https://doi.org/10.3389/fpsyg.2019.00475	156	22.3	3.08

Note.

TC – Total number of citations.

TC per year – Total number of citations per year;

NTC – Normalized Total Citations (calculated by dividing Total Citations by the average number of citations of articles published in the same year as the analyzed publication; a value above 1 indicates that the article is cited more frequently than the average of other publications from the same year.

Source: own study using the bibliometrix tool within the R software.

The works presented in Table 1 are characterized by a number of citations ranging from 156 to 493. High TCperYear values for most items indicate the continuing, current impact of the analyzed publications in scientific literature. In turn, the use of the NTC indicator allows for a more objective comparison of citation rates, eliminating the effect of time differences between older and newer publications.

The most influential work was that of Chen & Bellavitis (2020), for which the TC is 493 and the TC per year is 82.2 citations per year, indicating a significant role in the analyzed area. The high NTC value (9.245) demonstrates its key importance for the development of scientific discourse in the area of trust in the context of financial innovation. In this article, the authors assess the benefits of decentralized finance enriched with innovative solutions such as blockchain technology.

The next step was to analyze the countries of origin of the research centers declared by authors dealing with fintech and trust issues. An overview of the 30 countries with the highest number of publications in the studied area was presented, paying attention to the local and international scope of the research undertaken (Table 2).

Table 2.

Countries with the highest number of publications on fintech and trust

No.	Country	No. of articles	Freq	SCP	MCP	MCP ratio
1.	China	41	0.132	25	16	0.390
2.	India	35	0.113	32	3	0.086
3.	Malaysia	29	0.093	14	15	0.517
4.	United Kingdom	24	0.077	12	12	0.500
5.	USA	23	0.074	11	12	0.522
6.	Korea	19	0.061	13	6	0.316
7.	Spain	13	0.043	11	2	0.154
8.	Indonesia	12	0.039	11	1	0.083
9.	Australia	9	0.029	5	4	0.444
10.	Germany	8	0.026	8	0	0.000
11.	Pakistan	7	0.023	4	3	0.428
12.	Vietnam	7	0.023	7	0	0.000
13.	Brazil	6	0.019	5	1	0.167
14.	Italy	6	0.019	5	1	0.167
15.	Bangladesh	4	0.013	1	3	0.750
16.	Hungary	4	0.013	1	3	0.750
17.	Jordan	4	0.013	4	0	0.000
18.	Saudi Arabia	4	0.013	3	1	0.250
19.	Sweden	4	0.013	2	2	0.500
20.	Canada	3	0.010	3	0	0.000
21.	France	3	0.010	1	2	0.667
22.	Israel	3	0.010	1	2	0.667
23.	Portugal	3	0.010	3	0	0.000

Cont. table 2.

24.	Qatar	3	0.010	3	0	0.000
25.	Switzerland	3	0.010	1	2	0.667
26.	Bahrain	2	0.006	0	2	1.000
27.	Denmark	2	0.006	0	2	1.000
28.	Finland	2	0.006	0	2	1.000
29.	Morocco	2	0.006	1	1	0.500
30.	Poland	2	0.006	2	0	0.000

Note.

Freq – is a country's share in the total number of publications analyzed.

SCP (Single Country Publications) – the number of publications in which all authors are from the same country.

MCP (Multiple Country Publications) – the number of publications produced in international collaboration.

MCP_Ratio – an indicator expressing openness to international collaboration (something is shown or evidenced by a high level of international collaboration in research publications).

Source: own study using the bibliometrix tool within the R software.

According to the data in Table 2, most publications on fintech and trust come from China (the number of publications in the years under review was 41, accounting for 13.2% of all publications covered by the analysis). India (11.3%), Malaysia (9.3%), the United Kingdom (7.7%), and the USA (7.4%). These five countries account for more than half of the analyzed publications (English-language scientific articles and reviews) in the field of fintech and trust in 2016-2024 included in the Scopus and Web of Science databases. These data show that in the years under review, Asian countries were very active scientifically in the field of trust in financial innovation.

The SCP and MCP show which countries dominate independent research and which countries engage in international cooperation. The higher the MCP ratio, the more scientific articles have been produced as a result of international cooperation. A high MCP ratio (i.e., above 50%) was recorded in countries such as the US, the United Kingdom, Malaysia, but interestingly also in Bangladesh and Hungary, where the ratio reached 75%, which indicates that a large percentage of scientific articles were produced as a result of international cooperation.

On the other hand, countries such as India (8.6%) and Indonesia (8.3%) had a very low MCP ratio (below 10%). In several countries, taking into account the period under review, all publications on the subject in question were exclusively local in nature, e.g., in Germany, Vietnam, Jordan, Canada, and Poland.

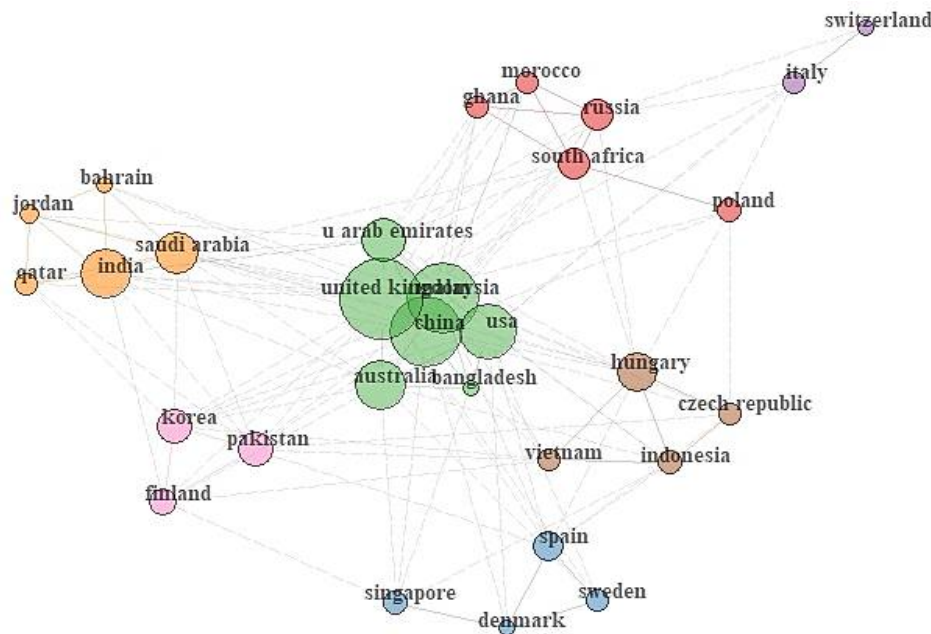


Figure 3. International cooperation network.

Source: own study using the bibliometrix tool within the R software.

Figure 3 shows the cooperation network between countries. The larger the node (circle), the greater the number of publications for which the country is responsible. The thickness of the connections (lines connecting the circles) corresponds to the intensity of cooperation, and the position in the network (i.e., location in the center of the network) shows which countries connect different research centers. The analysis showed the key role of research centers from countries such as China, the United States, the United Kingdom, and Australia due to their central location in the network. There are a large number of connections, which corresponds to the intensity of international cooperation. The diverse nature of the network shows that the issue of trust in the context of financial innovation is gaining importance globally. The topic is considered from an interdisciplinary perspective, combining various research themes.

It should be emphasized that the US and the UK are characterized by a high share of international publications (the MCP ratio exceeds 0.5). Their intensive cooperation with Asian and European countries can be observed. Malaysia (with a high MCP ratio) is an interesting example. Despite having fewer publications than China or India, this country plays an important role in the international cooperation network. Although there are fewer publications than in China or India, it is a country with strong links to many other countries. Other examples of countries with strong international cooperation are Hungary and Bangladesh. Pakistan, Australia, and Sweden also stand out with a balanced profile, where a significant proportion of publications are international. Indonesia and Vietnam are countries where publications are mainly produced locally, mostly independently, so their nodes will be relatively isolated in the network. Other examples include Germany, Vietnam, and Canada, where there are no strong links with other research centers.

Table 3.*Scientific journals with the highest number of publications in the field of fintech and trust*

No.	Sources	No. of articles
1.	Sustainability	12
2.	International Journal of Bank Marketing	11
3.	Journal of Financial Services Marketing	10
4.	Technological Forecasting and Social Change	8
5.	Heliyon	7
6.	IEEE Access	6
7.	Journal of Islamic Marketing	6
8.	Journal of Open Innovation: Technology Market and Complexity	6
9.	Journal of Risk and Financial Management	6
10.	Electronic Commerce Research and Applications	5
11.	Financial Innovation	5
12.	Fintech	5
13.	Journal of Asian Finance Economics and Business	5
14.	Research In International Business and Finance	5
15.	Sage Open	5

Source: own study using the bibliometrix tool within the R software.

An analysis of scientific journals in which the authors published articles in the field of fintech and trust (Table 3). The results show that the research is interdisciplinary and diverse. Journals related to banking, such as the International Journal of Bank Marketing (11 publications) or financial services marketing, such as the Journal of Financial Services Marketing, play an important role. A large number of publications are found in open access and wide-reaching journals, such as Sustainability (which ranks first with 12 publications) Heliyon (7 publications), and IEEE Access (6 publications). Publications also appear in journals with a narrower thematic focus, such as the Journal of Islamic Marketing. In addition, there are journals strictly related to the digital transformation of the financial sector, such as fintech and Financial Innovation.

The analysis covered the most frequently occurring author keywords (Table 4). The most frequently occurring keywords in relation to the chosen research area were fintech (255 articles), trust (83 articles), and blockchain (69 articles).

Table 4.*Most frequently occurring author keywords*

Author keyword	Number of articles
Fintech	255
Trust	83
Blockchain	69
Artificial Intelligence	26
Perceived risk	26
Financial technology	20
Financial inclusion	19
Adoption	17
TAM	16
Technology acceptance model	16
COVID-19	15
Social influence	15
UTAUT	15

Cont. table 4.

Cryptocurrency	14
Financial services	14
Fintech adoption	13
Malaysia	12
Mobile payment	12
Peer-to-peer lending	12
Perceived trust	12
Behavioral intention	11
Fintech services	11
Innovation	11
Bitcoin	10
Intention to use	10
Islamic Fintech	10
Perceived usefulness	10
Privacy	10
Blockchain technology	9
Crowdfunding	9

Source: own study using the bibliometrix tool within the R software.

An analysis of the co-occurrence of author keywords allowed us to identify the main research topics in the literature on fintech and trust. The keyword network reveals several distinct thematic clusters (Figure 3).

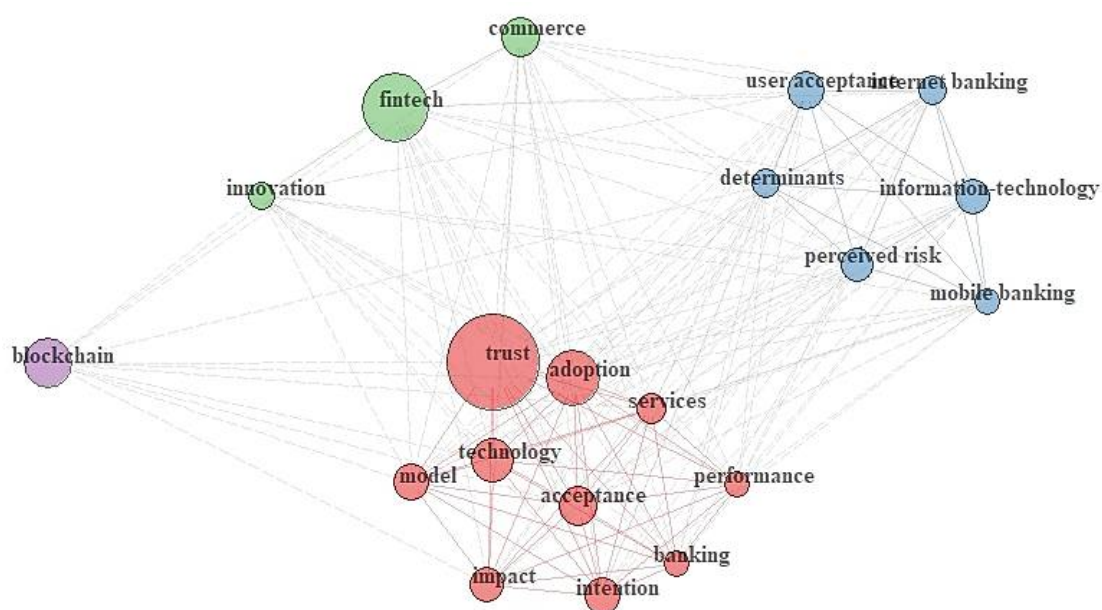


Figure 3. Co-occurrence network based on author keywords.

Source: own study using the bibliometrix tool within the R software.

The nodes in the diagram refer to the most frequently occurring author keywords, and the thickness of the edges refers to the co-occurrence between keywords within the same publications. Individual thematic clusters are marked with different colors. The diagram shows that four main research clusters can be distinguished.

The red (most numerous) cluster in the very center contains the concept of trust (the most frequently occurring author's keyword). This term is found in the same cluster as such author's keywords as adoption, acceptance, technology, intention, impact, and model. This group

reflects the key importance of trust in the process of adoption and adaptation to the use of modern technologies in financial services (Broby, 2021). Trust is a key factor determining the degree of use of digital solutions by society (Khera et al., 2022).

The green cluster contains references to keywords such as fintech, innovation, and commerce. This shows the importance of research into modern business models and digital transformation in finance. The next cluster, purple, illustrates research into blockchain technology (Kowalski et al., 2021, Cai 2021). This cluster shows a strong connection with the two previous ones, which included the topics of fintech and trust. Another cluster (blue) concerns aspects related to technologies and their use. It includes keywords such as mobile banking, information technology, perceived risk, and user acceptance. The research topics in this area illustrate the growing importance of risk perception and factors determining the adaptation of technological solutions among users of modern financial services.

The results suggest that researchers devote considerable attention to behavioral and technological issues, demonstrating the role of trust in the process of accepting financial innovations (Bajunaied et al., 2023; Chan et al., 2022). The second pillar of research is the sphere of innovation and organization, which refers to research on the impact of financial innovations on business models implemented in entities, taking into account the perspective of user trust (Elliott et al., 2021). The network of keyword interdependencies allows us to conclude that the topic of fintech and trust has an interdisciplinary dimension and requires consideration of economic, social, and technological perspectives.

4. Discussion and Implications

The analysis showed that interest in the role of trust in the context of fintech is constantly growing, with researchers discussing various perspectives. Countries such as China, India, and Malaysia have been shown to be leaders in this field, accounting for over a third of the research in this area based on quantitative publication analysis, collectively accounting for more than a third of all publications. Although China and India focus primarily on domestic research, other research centers in countries such as Malaysia, the United Kingdom, and the United States demonstrate significant international collaboration. Smaller countries also demonstrate significant international collaboration activity, including Bangladesh and Hungary. The collaboration network analysis highlights two distinct models of research activity: nationality focuses hubs (represented by China and India) and internationally connected network (centered around the USA, UK, and Malaysia). Finally, the keyword and thematic analysis identifies three main research clusters:

1. Technological foundations of trust, focusing on *fintech, blockchain, and security*.
2. Customer behavior and adoption, exploring *trust, perceived risk, and digital banking*.
3. Financial inclusion and innovation, linking *fintech development* with *social and ethical aspects* of trust.

These findings suggest that the field of *fintech and trust* is interdisciplinary and globally diverse, integrating perspectives from technology, economics, and behavioral sciences.

The results of this study highlight several important implications for both the academic community and the beneficiaries of the financial sector. Trust is not a soft value. It is a critical asset for the development of the financial system. The regional concentration of fintech and trust research, particularly in Asia, shows that the region is becoming a driving force in digital finance innovation. However, the relatively low international collaboration ratio in some leading countries, such as China and India, indicated an untapped potential for cross-border research partnerships. Strengthening such cooperation leads to more comparative studies and broader theoretical frameworks that capture cultural and regulatory differences in trust formation. The high visibility of interdisciplinary journals (such as *Sustainability* and *Technological Forecasting and Social Change*) demonstrates that the study extends beyond traditional finance. Integrates insights from technology, psychology, marketing, and ethics, reflecting the complex nature of digital trust in financial ecosystems. From the point of view of the keyword trust, we can observe its combination with many aspects. The evolving research themes from blockchain and security to consumer trust and financial inclusion suggest a shift toward human centered perspectives in fintech research. This evolution emphasizes that technological advancement alone is insufficient. Trust transparency and user confidence remain central to sustainable fintech development. The findings encourage greater international collaboration, interdisciplinary dialogue, and policy-relevant research to support a more secure and inclusive financial landscape.

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ARTIFICIAL INTELLIGENCE AS A TOOL SUPPORTING THE PROCESS OF MANAGING A FOOTBALL TEAM AT THE TRAINING LEVEL

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Purpose: The reason for writing this article is to explore various areas where artificial intelligence can be applied and see what the results are.

Design/methodology/approach: In his work, the author focused primarily on examining the literature on AI technology and the topic of creating models for soccer training. Additionally, the author reviewed the use of technology in soccer training journals to understand the opinions of the soccer community on the subject.

Findings: The author noted that ready-made models are already being developed to meet the needs of top football teams regarding data analysis, which can help optimize the training and team management process. At the same time, the use of this simple technology can be observed in academies specializing in training youth teams.

Research limitations/implications: While you can find articles on the creation of AI models, you need to remember that these are largely solutions for specific clubs, and therefore knowledge about them is, for obvious reasons, limited only to a narrow group of interested people.

Practical implications: The increased use of artificial intelligence could have a significant impact on the future of not only football (which is the subject of this article) but also sport in general.

Originality/value: This article is an overview and analysis of the issue of AI in football, which, despite its popularity in many leagues, is still something new and worth considering.

Keywords: Football Club Management, AI in Sport, AI in Football, Data analyse in sport.

Category of the paper: Management, Management in sport.

1. Introduction

These days, professional football teams face a number of challenges. The biggest of these, to paraphrase the words of a Polish footballer "There are no weak teams left in Europe" is, of course, intense competition. The stronger the team, the more matches there are to be played, as league competitions must also include matches in various national and international cups,

individual players' performances in national team matches, and so on. High performance requirements, coupled with the simultaneous growth of already vast data streams (from player tracking, training analysis, match analysis), require a comprehensive approach to team management. This is essential to selecting the optimal lineup for each match, with players in peak form in a given microcycle, along with the appropriate formation.

Technologies such as artificial intelligence offer significant opportunities for clubs, providing them with advantages, streamlining decision-making, player selection, and improving squad training. This article provides an overview of AI's use and potential applications in football team management (including selection and formation), match and training management (tactics, performance, collective behavior), and training organization (individual training, workload management, injury prevention). The current state of research/literature is reviewed. Practical applications and organizational implications for clubs are also presented, and the author explores the potential for implementing developments in this field.

Football is arguably one of the most complex team sports in the world, operating on multiple levels:

- Sporting (tactics, player performance, fitness/injuries) – It combines individual physical and technical behavior, collective tactical coordination, opponent adaptation, and a high level of uncertainty (related to random factors such as a player's reaction to pressure, acclimatization to a new environment, etc.).
- Administrative (transfers, contracts, scouting) – Selection and observation of players, not only in terms of how a given player behaves on the pitch, their results, etc., but also whether their game fits the current club concept/philosophy and their adaptability to the current player combination. As coach Eelco Schattorie said in an interview, "You should never choose the best player for every position, but the best combination of players who fit together" (Schattorie, 2023).
- Commercial (sponsorship, fan engagement, media).
- Operational (logistics, planning, data management).

In this article, the author focuses on aspects of coaching thus touching on the sporting and, to some extent, administrative aspects of transfers and the elements surrounding this topic. While the author's approach might seem simplistic, upon closer inspection, statistical football analysis itself attempts to provide quantitative answers to questions about various aspects of the game. In particular, these include characterizing the playing styles of players and teams, assessing the impact these teams have on the pitch, and making temporal and counterfactual predictions about player actions (Tuyts, Omidshafiei, Muller, Zhe Wang, Connor, Hennes, 2020).

Traditional coaches and management have long relied on video recordings, statistical summaries, and coach experience to make decisions about lineup selection, tactics, training load, and recovery.

However, in the last decade, the combination of large-scale tracking data, wearable sensors, computer vision, cloud computing, and advanced machine learning has created new opportunities.

Artificial intelligence broadly encompassing machine learning, deep learning, computer vision, and optimization algorithms-offers the potential to improve decision-making, support real-time analytics, personalize training, optimize team formations, and even automatically generate new tactical suggestions. The purpose of this article is to synthesize the scientific evidence and practical implementations of AI in football, with a focus on three broad areas:

- team management and player selection,
- match/training analysis and tactical decision-making,
- training organization, including physical load, regeneration and injury prevention.

In the past, the coaching staff consisted primarily of a coach, an assistant coach, and a person responsible for physical preparation and wellness. If we were to look at the coaching staffs of professional football teams today, the number of players could be considered a new team, including a bench. Analyst, Sporting Director, assistant analysts, assistant coaches, second and third coaches, etc. The multiplication of positions is dictated by the demands of modern football, where the sheer volume of issues and data requires greater specialization than ever before.

2. Team management – selecting players and formations

Tactical preparation is crucial in football. Decisions regarding formation, opponent analysis, set-piece patterns, substitutions, pressing, and player roles are increasingly data-driven. Creating the right AI model can help identify the most appropriate players and combinations for a given team context.

For example, in the article *Intelligent team formation and player selection: a data-driven approach for football coaches* the authors have developed a machine learning framework that supports coaches by optimally matching players to positions and selecting team formations based on historical match performance indicators (Nouraie, Eslahchi, Baca, 2023). As a starting point (i.e. the data on which the model was based) in this study, the SOFIFA dataset was used, which is available and published annually (SOFIFA Players FIFA 23).

This dataset includes most of the world's adult football players, along with their performance in various football-related skills (such as shooting, passing, ball control, etc.), contract information, and more. FIFA experts (scouts) have compiled these attributes into a single dataset, with each parameter assigned a specific numerical value. They closely monitor player performance throughout the season and assign a score from 1 to 100 to each player's individual attribute.

The model adopted depends on the coaching staff. For example, the authors (Uzochukwu, Enyindah, 2015) to develop a player selection model, they used neural network techniques, where the attributes needed for player selection are analysed in four main categories, encompassing four aspects: technique, speed, physical condition, and endurance. Of course, the word "speed" can be misleading here, so it's important to note that this isn't about the classic definition of speed, i.e., how fast a player can run on a straight line. Speed was assessed based on reaction time, how quickly a player moves with the ball while dribbling, and take-off/acceleration. The remaining three parameters were calculated similarly, and this comprehensive data was used to select the lineup for the match.

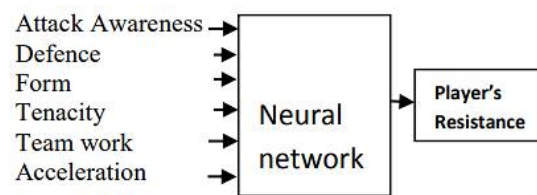


Figure 1. Architecture of a neural network model for testing soccer player endurance.

Source: (Uzochukwu, Enyindah, 2015).

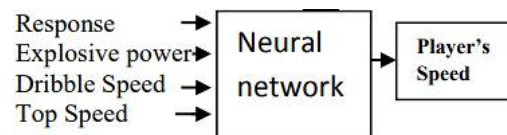


Figure 2. Neural network model architecture for player velocity status.

Source: (Uzochukwu, Enyindah, 2015).

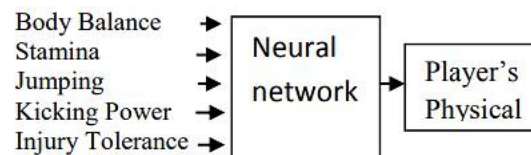


Figure 3. Neural network model architecture for the player's physical state.

Source: (Uzochukwu, Enyindah, 2015).

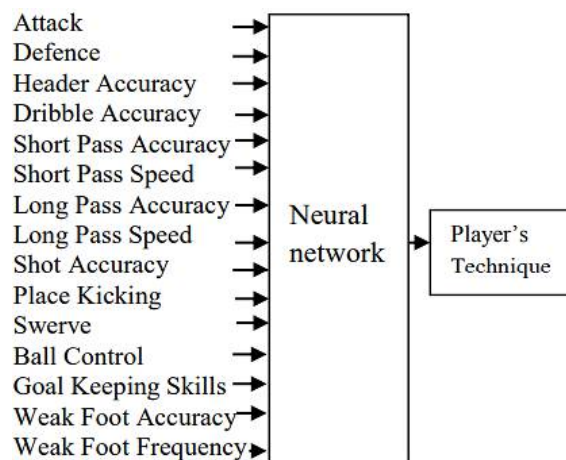


Figure 4. Neural network model architecture for player technique.

Source: (Uzochukwu, Enyindah, 2015).

The architecture/model outline presented above is, of course, just one of many, as it all depends on how the coach (training staff) approaches the issue, meaning what they pay attention to. This influences the specific data collected and the data mining method, as described by the authors (Evwiekpaefe, Bitrus, Ajakaiye, 2020).

For one coach, short passing skills will be more important than long crosses, so a "weighting" system can be adopted, with more important parameters having higher values than others. At the same time, this also depends on whether the coach selects players for a given formation (e.g., 4-5-1, 3-5-2) or adapts the formation based on specific players.

For example, if you have a strong wing-back formation with at least three solid centre-backs, it's worth considering a 3-5-2 with wing-backs who are strong enough to support both defensive and offensive efforts throughout the entire match (or for a significant portion of the match). By analysing historical match data (opponent behaviour, spatial patterns, passing networks) and adapting it to the team's strengths and weaknesses, you can optimize your formation and tactics.

In the article *Predicting Football Team Performance with Explainable AI: Leveraging SHAP to Identify Key Team Level Performance Metrics* (Moustakidis, Plakias, Kokkotis, Tsatalas, Tsaopoulos, 2023; Moustakidis et al., 2023) explainable AI (XAI) techniques were used to identify which team-level performance indicators predict success. In the article [<https://arxiv.org/pdf/2310.10553>], the authors focused on corner kicks themselves when developing their model, arguing that they offer coaches the most direct opportunities for interventions and improvements. As you can see, in addition to the fact that there can be several models developed, they can also cover comprehensive tactical analysis, including formation and tactic selection, as well as a subset of them (corners, free kicks, etc.).

3. Tactics

One of the largest areas of application of artificial intelligence is the analysis of so-called tactical behavior using spatial-temporal tracking data (e.g., position of players and the ball, movement of a player with the ball, movement of a player without the ball).

In the article *Mapping football tactical behavior and collective dynamics with artificial intelligence: a systematic review* (Teixeira, Maio, Pedro Afonso, Encarnação, Machado, Morgans, Barbosa, Monteiro, Fort, Ferraz, Branquinho, 2025) the author summarized 32 studies and highlighted how artificial intelligence techniques (neural networks, neural networks, variational autoencoders, graph-based metrics) are used to obtain information on formation, team coordination, passing networks, space control and player interactions.

For example, one study used graph metrics (betweenness centrality, clustering coefficient) for passing networks to infer which players are central during possession phases, allowing coaches to emphasize or restructure player roles accordingly. This allows, for example, to determine whether, after winning the ball back, it is passed into the opponent's half or slowly played. If it is passed, which player does it? If it is passed, which side of the pitch is played more often, and so on.

Based on such analysis, decisions can also be made about whether to play against an opponent who presses high. Whether to open up play from the goalkeeper to the defenders or whether to utilize long passes is preferable. Whether to trade shots against a given opponent with a high defensive line, or whether it is better to position your defense lower and wait for opportunities to counterattack.

More advanced models can help coaches predict which tactical styles are most likely to succeed and which require modification. Furthermore, generative models are now able to simulate and propose alternative formations or player patterns (Wang, Tuyls, 2025).

4. Training

Training, a key aspect of squad management, encompasses both physical and tactical preparation (learning how to react to specific situations on the pitch, positioning, etc.). Artificial intelligence can bridge the gap between match analysis and training session design.

Even in lower leagues and youth teams, smart sports camera systems are already very popular. These systems, used to record matches, track ball movement, eliminating the need to manually control the camera to follow the action. Furthermore, built-in logic "pulls out" key moments from the recording, such as shots on goal or a goal, providing the analyst with a pre-prepared video that allows them to analyse matches more effectively without having to rewind the entire video. This shortens the time spent watching the match, allowing them to focus more on the important elements and prepare a more thorough analysis.

Furthermore, such recordings can be used to analyse both their own team and the opponents' performance. By transmitting data from match/tracking systems to training planning software, clubs can identify training tasks that reflect the tactical, physical, and team demands of real-world matches. For example, by recognizing opponents' play patterns (e.g., when opponents press high or defend deep), it is possible to design training units specifically for a given opponent.

Additionally, computer vision processing and data from wearable sensors or AI tracking of each player individually enable the creation of positional heat maps (i.e., analysis of the area a given player has travelled through) and deviations from optimal movement corridors (unusual plays and positional drifts). This allows, for example, analysis of whether a winger's drop into

midfield has been effective or whether it has created a threat to his own team by creating a gap in the formation.

In addition to analysing match behaviour, artificial intelligence can optimize training sessions, monitor player load and fatigue, and propose personalized training units (Bucea-Manea-Țoniș, Vasile, Trușcă, Stănescu, 2025).

Going further, one could attempt to analyse a player's weak points and select appropriate individual training. At one time, Hertha Berlin employed three goalkeeping coaches to improve their goalkeepers' play, each with a different role. One was responsible for analysing and improving the player's grip, another solely for positioning, and the third for fall technique (on the one hand, to prevent injuries and at the same time develop positions that would allow the goalkeeper to get back up as quickly as possible after a fall). Analysis of the goalkeeper's shots and conceded goals in a specific area of the goal could be implemented immediately, to analyse, for example, which side of the goalkeeper (left/right) is the weaker side, as shown in the Piotr Kruszewski' article (Kruszewski, 2025).

5. Injuries

The increasing number of matches players must play (especially those in the highest domestic leagues) has put them at greater risk of injury than ever before. This translates to high match demands and sometimes short recovery periods. The use of artificial intelligence (AI) opens up interesting prospects for predicting injury risk and performance in team sports. A better understanding of AI techniques and the sports in which AI is used is undoubtedly warranted (Claudino, Capanema, Vieira de Souza, Serrão, Pereira, Nassis, 2019).

Here, too, injury prevention methods can vary. Medical knowledge is fundamental, of course, but knowledge from other sources is equally important: The athlete's injury history how often they were injured, at what times of the season, and what type of injury it was.

Additionally, you can approach the topic from a different perspective: Which periods of the season caused the most injuries? Which training sessions were more taxing, allowing you to reduce the number of injuries through appropriate micro- and macro-cycle design.

6. Future Direction

Of course, speculation remains as to how AI will develop in this field. One development direction is enabling AI systems to operate in real time during matches (or at halftime) to support tactical changes. This requires ultra-low latency tracking, fast models, and integration with coaches' decision-making processes.

The growth in data sources and computing power may also allow for simulations of our team's match against its nearest opponent, helping us choose the best gameplay scenario (Scott, Fujii, Masaki Onishi, 2021).

The question now arises: has high-quality training so far involved, among other things, hiring the right staff (as it was often said that a coach would take "his" people with him after moving to another club), or will the opposite trend occur now? The growing role of artificial intelligence will mean there will be no need to hire as many people (e.g., analysts), which will significantly change the structure of clubs, and this refers only to the coaching staff itself.

Of course, there are certain risks to implementing such solutions, including ethical ones. All data maintained by each team must be stored somewhere. If the data is to be accessible to staff anywhere in the world, a cloud-based solution seems logical. But what if such data leaks? What impact will it have on players and their careers if, for example, information about a player's weaknesses becomes public? This raises numerous legal and ethical questions that will ultimately need to be answered.

7. Summary

Integrating AI into football team management, tactical and training analysis, and training organization is no longer theoretical—it's already happening. AI enables clubs to optimize player selection, formations, tactics, training load, and recovery in ways previously impossible.

The scientific literature, including systematic reviews and applied research, indicates clear potential and early successes. However, practical implementation requires a robust data infrastructure, organizational change, trust in algorithmic results, interpretability, and strong governance. The future holds opportunities for real-time decision support, multi-agent simulations, personalized training, and broader club-level implementation. For football clubs willing to invest, AI can become a strategic asset—changing how teams prepare, play, and recover.

If we were to summarize this article and the conclusions it draws, the only common element between each model is, of course, data. Everything else—the method of acquisition, the type of data, and the scope of its use—depends primarily on the strategy adopted by the team.

Table 1.*Possible methods for conducting analyses and collecting data*

Data source	Detail	Areas of use
Sports portals, portals like SOFIFA etc.	1	Player selection during purchase based on parameters such as: • Review of overall on-field experience. • Insight into playing experience in a given position. • Injury history.
Video recordings – this assumes the use of intelligent forms of match recording. Therefore, the level of detail will depend on the specific information collected.	1-2	Tactics selection, development of training units, and individual training sessions based on the following information: • Comprehensive analysis of team play, including: – Key situations, – Heat map of player movement, – Team statistics (passes, shots, fouls, etc.). • Individual player performance assessment: – Area of movement on the pitch, – Behavior in key situations, – Preliminary analysis of player fatigue based on monitoring game intensity over time.
Body sensors, advanced databases.	3	Transfers, tactics, and training methods are selected based on: • Player physical parameters, • Player health parameters, • Injury history and potential injury risk.

In his analysis, the author adopted a three-point scale for detail column. The higher the rating, the greater the detail and the potential for creating more complex models. Of course, these elements can be combined in various ways, yielding more complex datasets. However, it's important to remember that the more complex the model, the greater the knowledge required to analyse it. This question remains open for now: Will the amount of data eventually become so large that Big Data in sports is only a matter of time?

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APPLICATION OF PORTFOLIO THEORY TO MINIMISE INVESTMENT RISK IN THE EQUITY MARKET

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Purpose: This article examines the utility of Markowitz portfolio theory in the context of minimum risk portfolio construction in minimising investment risk using a two-component stock portfolio as an example. The paper will present an example of an investment strategy that minimizes investment risk.

Design/methodology/approach: The study covered 18 companies included in the Warsaw Stock Exchange's main index, the WIG20. Two-component portfolios were constructed based on PKN Orlen, as the company with the highest capitalisation. As a result, 17 two-component portfolios were considered by determining the shares of companies in portfolios with minimum risk. A simulation was applied to verify whether the recommended shares determined on the basis of historical data actually led to a reduction in investment risk in the analysed period. Measures of descriptive statistics used in the calculations required obtaining data on monthly returns for the period January 2020-March 2023, and the portfolio analysis itself concerned the period January 2021-March 2023.

Findings: The simulation showed that investing in a recommended portfolio, i.e. one in which we review the composition and/or shares of the companies in the portfolio each month, generally performed better in terms of risk than investing throughout the period in a two-component portfolio with a given composition but modified only by the shares of the companies in the portfolio.

Practical implications: As a result of the simulation, the application of Markowitz portfolio theory to minimise investment risk was confirmed. The analysis period covering the years 2020-2023, characterised by high uncertainty, further confirms the validity of building an investment portfolio based on the assumptions of selecting companies for the minimum variance portfolio (MVP).

Originality/value: The paper gives an example of an investment strategy based on adjusting from period to period the composition and/or holdings of companies in a two-component portfolio based on the assumptions of minimum-risk portfolio construction.

Keywords: portfolio theory, minimum variance portfolio, investment risk, Harry Markowitz, investment decisions.

Category of the paper: research paper.

JEL Classification Codes: G11.

Introduction

At the beginning of the second half of the 20th century, the investment community struggled with the lack of risk measures. At that time, H. Markowitz developed a basic portfolio model that specified an expected rate of return for a portfolio of assets and an expected risk measure. He pointed out that the variance of returns previously used was an incorrect measure of portfolio risk. Markowitz introduced a formula for calculating the variance of a portfolio, thus indicating how to effectively diversify the portfolio and how to determine the importance of investment diversification in reducing the total risk in a portfolio. The model is based on numerous assumptions about investor behaviour concerning, among other things, probability distribution, utility maximisation and a preference for higher expected returns.

Portfolio theory facilitates decision-making under conditions of uncertainty in securities investments, as it is based on two criteria: return and risk. The choice in constructing an investment portfolio relates to the degree of risk acceptance relative to the expected rate of return, whereas the greater the risk, the greater the return. Investment preferences vary from investor to investor, they depend on, among other things:

- the profit increment and the rate of return,
- the holding time of the invested capital and the liquidity of the investment,
- the economic, social and political environment,
- the individual characteristics of the investor.

Portfolio theory allows the shares of companies in a minimum variance portfolio (MVP) to be determined. An investor focused on achieving returns with the lowest possible risk will consider efficient portfolios dominant over inefficient portfolios. Figure 1 shows MVP and an example of portfolio A dominating (efficient) and portfolio B (inefficient).

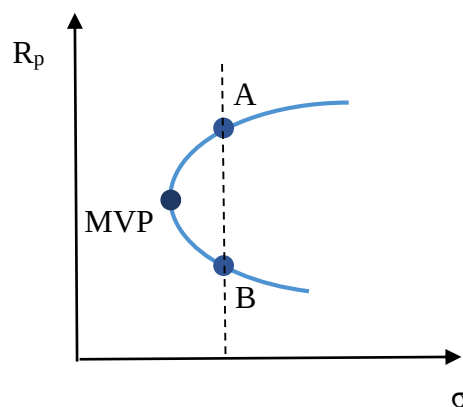


Figure 1. Minimum variance portfolio (MVP), efficient portfolio and inefficient portfolio.

Source: Bielska (2023).

Figure 1 shows MVP and an example of portfolio A dominating (efficient) and portfolio B (inefficient). Portfolios A and B have the same risk (σ), but portfolio A achieves a higher return (R_p) and therefore dominates portfolio B (stochastic portfolio dominance).

Portfolio theory and its modifications

Portfolio theory is considered to have originated in 1952, when Harry Markowitz published an article detailing the phenomenon. He is widely recognised as the forerunner of this theory. According to some researchers, in doing so, Markowitz opened a new chapter in the history of financial development. The basic idea of this theory is to aim for an investment portfolio with the highest possible rate of return and with the smallest possible spread of investment outcomes (Markowitz, 1952).

Markowitz assumed the rationality of the investor's behaviour, who makes decisions by maximising his utility. Maximising the utility function is done by maximising the portfolio mean (i.e. return) or minimising the portfolio standard deviation (i.e. risk).

Markowitz's portfolio theory assumes that the means and covariances of the returns on the underlying assets are known, so one would have to rely on forecast data. In practice, these are unknown and must be estimated from historical data. In the absence of normality, researchers have proposed modifications to portfolio analysis models. Lai (1991) defined portfolio selection with skewness based on solving a polynomial objective programming problem that incorporates investor preferences. Various risk measures have also been proposed: for example, mean absolute deviation risk (Konno, Yamazaki, 1991) and conditional VaR (Rockafellar, Uryasev, 2000) which allows the formulation and solution of a portfolio selection problem using linear programming techniques. Goldfarb & Iyengar (2003) proposed the use of uncertainty structures, to deal with the sensitivity of optimal portfolios to statistical errors in market parameter estimates.

In addition, limitations associated with mean-variance (MV) optimisation include: concentrated asset class allocation, inability to account for skewness and kurtosis, and lack of risk diversification. Numerous modifications have been developed in response to these limitations, among which it is worth mentioning: the stochastic linear-quadratic (LQ) control proposed by Zhou and Li (2000), the inclusion of the time dimension by Fahmy (2020). Ötken et al. (2019), on the other hand, added further constraints to the MV concept: cardinality, sector capitalisation and tracking error. King extended the model with asymmetric risk measures (King, 1993), Cesarone et al. explored the Markowitz limited asset model by introducing cardinality constraints (Cesarone et al., 2013), and Guerard et al. extended the model with a multi-objective portfolio optimisation problem (Guerard et al., 2018). In addition, some authors have suggested that portfolio selection is a multi-criteria choice problem

(Ogryczak, 2000), and some have included environmental and social issues in portfolio optimisation (Liagkouras et al., 2020).

Despite the development of more sophisticated models, the model based on Markowitz's portfolio theory is still widely used in practice for active portfolio management. Fabozzi et al. provided an overview of the contributions to portfolio choice theory from an operations research and finance perspective. In their paper, Fabozzi et al. examined the classical mean-variance problem, the mean-VaR model and the mean-CVaR model, and reviewed optimal estimation methods together with a robust Bayesian approach (Fabozzi et al., 2010).

According to the authors, given the risks that have occurred in recent years, namely the coronavirus pandemic and the increased political risk associated with the war in Ukraine, it was reasonable to test the effectiveness of a model based on minimum-risk portfolio construction in the context of investment risk minimisation.

Methodology/Research methods

The aim of the study was to investigate the application of Harry Markowitz's portfolio theory to minimise investment portfolio risk. The study set out a research hypothesis as follows: an investment strategy built on the basis of Harry Markowitz's portfolio theory reduces investment risk.

We determine the shares of companies in the minimum-risk portfolio by calculating the vector w by multiplying the inverse variance-covariance matrix and the vector I :

$$w = C^{-1}I \quad (1)$$

where:

w – a vector with $n+1$ components, of which the first n components are the shares in the MVP,

I – a vector with $n+1$ components, of which the first n components are 0 and the last one is 1,

C^{-1} – inverse matrix C ,

C – variance-covariance matrix of dimension $(n+1) \times (n+1)$, the elements of which are defined as follows:

$$c_{ii} = 2\sigma_i^2, \quad i = 1, \dots, n; \quad (2)$$

$$c_{ij} = 2\sigma_i\sigma_j\rho_{ij}, \quad i, j = 1, \dots, n, \quad i \neq j \quad (3)$$

$$c_{i,n+1} = c_{n+1,i} = 1 \quad i = 1, \dots, n; \quad (4)$$

$$c_{n+1,n+1} = 0 \quad (5)$$

In the case of a two-component portfolio, we can apply the formulas:

$$w_1 = \frac{\sigma_2^2 - \sigma_1\sigma_2\rho_{12}}{\sigma_1^2 + \sigma_2^2 - 2\sigma_1\sigma_2\rho_{12}} \quad (6)$$

$$w_2 = \frac{\sigma_1^2 - \sigma_1\sigma_2\rho_{12}}{\sigma_1^2 + \sigma_2^2 - 2\sigma_1\sigma_2\rho_{12}} \quad (7)$$

We determine the portfolio variance according to the formula:

$$V_p = \sum_{i=1}^n w_i^2 \sigma_i^2 + 2 \sum_{i=1}^{n-1} \sum_{j=i+1}^n w_i w_j \rho_{ij} \quad (8)$$

where:

V_p – variance of portfolio returns,

σ_i – standard deviation of the return on shares of the i-company,

ρ_{ij} – the correlation coefficient of the i-th and j-th company's share returns.

The portfolio's rate of return is represented by the formula:

$$R_p = \sum_{i=1}^n w_i E(r_i) \quad (9)$$

where:

R_p – expected rate of return of the portfolio,

W_i – share of i-th company in the portfolio,

$E(r_i)$ – expected rate of return of the i-th company's shares.

The period of analysis was taken as: January 2020 to March 2023. The portfolio analysis itself concerned the period: January 2021 to March 2023. The subject of the analysis was the monthly returns of companies included in the main index of the Warsaw Stock Exchange - WIG20. Only those companies that were continuously included in the WIG20 index during the period under study were included in the study. Allegro.EU SA and Pepco Group N.V. were therefore excluded. The portfolio analysis was conducted on the basis of 18 companies (table 1).

Table 1.

Companies included in the WIG20 index

Full name of the company	Short name of the company	3-letter abbreviation
Polski Koncern Naftowy Orlen S.A.	PKN ORLEN	PKN
Alior Bank S.A.	ALIOR	ALR
Mbank S.A.	MBANK	MBK
Bank Polska Kasa Opieki S.A.	PEKAO	PEO
Powszechna Kasa Oszczędności Bank Polski S.A.	PKO BP	PKO
Santander Bank Polska S.A.	SANPL	SPL
Powszechny Zakład Ubezpieczeń S.A.	PZU	PZU
Dino Polska S.A.	DINOPL	DNP
Pepco Group N.V.	PEPCO	PCO
Allegro.eu S.A.	ALLEGRO	ALE
KGHM Polska Miedź S.A.	KGHM	KGH
Jastrzębska Spółka Węglowa S.A.	JSW	JSW
LPP S.A.	LPP	LPP
CD Projekt S.A.	CDPROJEKT	CDR
Asseco Poland S.A.	ASSECOPOL	ACP
Grupa Kęty S.A.	KETY	KTY
Kruk S.A.	KRUK	KRU
Orange Polska S.A.	ORANGEPL	OPL
Cyfrowy Polsat S.A.	CYFRPLSAT	CPS
PGE Polska Grupa Energetyczna S.A.	PGE	PGE

Source: Bielska (2023).

The possibility of minimising risk by constructing two-component portfolios with minimal risk was examined first. The study was limited to two-component portfolios containing the shares of PKN Orlen SA. Thus, 17 binary portfolios were analysed by determining the shares of the respective companies in the MVP, the minimum risk of these portfolios and the average return of the MVP were calculated. A simulation was then carried out, which consisted of selecting the portfolio with the lowest minimum risk among the portfolios analysed in a given month and taking it as a recommendation for investment in the following month. In each month, the composition of the portfolio and/or the share of companies in the MVP was changed. Thus, it was checked what rate of return the recommended portfolio would realise in order to finally count the standard deviation of the monthly returns of the recommended portfolio to assess risk. The risk analysis procedure for the two-component portfolios is presented in table 2.

Table 2.

Analysis steps for applying Markowitz theory to two-component portfolios

I. Selection of portfolio companies
– one of the portfolio companies is assumed to be PKN Orlen SA, – the second company in the portfolio would be a company listed in the WIG20 index continuously between January 2020 and March 2023, – thus, 17 two-component portfolios were analysed.
II. Analysis period
– January 2020 - March 2023, – analysis on a monthly basis, – analysis of two-component portfolios for the period January 2021-March 2022, – average return, standard deviation of returns and correlation coefficient were calculated for each month for the period of the last 12 months.
III. Calculation of basic measures of descriptive statistics
– monthly rate of return was calculated for each company, followed by average monthly returns and standard deviation of returns, – the correlation coefficients of the returns of PKN Orlen with the other companies in the WIG20 index were calculated.
IV. Structuring two-component portfolios with minimal risk
– the shares of companies in the minimum-variance portfolio were determined for each of the 17 two-component portfolios, – the average return of the minimum-variance portfolio was determined.
V. Simulation
– for each month in the period January 2021 - March 2023, out of the 17 analysed two-component portfolios with minimum risk, the one with the lowest minimum risk was selected, – determined shares of companies in the selected minimum-variance portfolio were accepted as recommended to the investor and it was checked what rate of return this portfolio would have realised in a given month, – in each month of the portfolio analysis the composition of the portfolio and shares of portfolio companies were verified.
VI. Analysis of effectiveness
– on the basis of the calculated rates of return realised by the selected portfolio at the recommended shares, the standard deviation of the returns of the recommended portfolio for the period January 2021 - March 2023 was determined, – for each of the 17 minimum-variance two-component portfolios, the monthly rates that would have been achieved with the recommended shares as well as the standard deviation of the returns for each of the two-component portfolios over the analysed period were calculated, – the standard deviation of the returns of the portfolio chosen by the investor (step 5) was compared with the other minimum-variance two-component portfolios, – for each of the portfolios, the standard deviation of the realised returns of the portfolio was compared with the standard deviations of the returns of the companies included in that portfolio.

Source: Bielska (2023).

The application of Markowitz theory required the calculation of returns and standard deviations of the returns of the companies studied, as well as the correlation of returns. The analysis was based on monthly returns. Average returns, standard deviations and return correlations were calculated for the last twelve months. Quoted return data for the surveyed companies comes from stooq.com.

Results

On the basis of measures of descriptive statistics, the shares of companies in the two-component portfolios with minimum risk were determined and the minimum risk for the individual portfolios for the period: January 2021-March 2023 was determined. It is worth noting that the minimum portfolio risk thus determined was lower than the risk of the individual companies as measured by the standard deviation of returns. The average returns of the minimum risk portfolios were also calculated as weighted averages of the shares of these companies in the minimum risk portfolio and the average return of the individual companies. Similarly, the returns of the portfolios were calculated taking into account the recommended shares of the minimum-risk portfolios (calculated on historical data) and the returns obtained by the companies concerned in a particular month. The shares of the companies in the MVP were therefore a recommendation to the investor, who, by spreading capital across the companies, achieved a specific rate of return on the two-component portfolio. Then, for each month, the portfolio that had the lowest minimum risk out of the 17 portfolios analysed was selected and treated as a recommendation for the risk-minimising investor.

Table 3 summarises the standard deviations of the returns of the two-component portfolios realised in the period January 2021-March 2023 on the basis of the recommended shares of companies calculated for the MVPs. In addition, the standard deviations of the returns of the company that constituted the two-component portfolio alongside PKN Orlen are presented.

Table 3.

Risk of two-component portfolios compared to the return risk of the companies in the portfolios

Portfolio	I company in the portfolio	II company in the portfolio	standard deviation of the returns of the two-component portfolio realised between January 2021 and March 2023	standard deviation of returns of shares of a company included in the two-component portfolio with PKN realised in the period January 2021-March 2023
Portfolio 1.	PKN	ALR	0,0998	0,1595
Portfolio 2.	PKN	ACP	0,0572	0,0535
Portfolio 3.	PKN	CDR	0,0829	0,1282
Portfolio 4.	PKN	CPS	0,0684	0,0709
Portfolio 5.	PKN	DNP	0,0851	0,0883
Portfolio 6.	PKN	KTY	0,0715	0,0808

Cont. table 3.

Portfolio 7.	PKN	JSW	0,0972	0,2006
Portfolio 8.	PKN	KGH	0,0841	0,0963
Portfolio 9.	PKN	KRU	0,0948	0,1325
Portfolio 10.	PKN	LPP	0,0980	0,1541
Portfolio 11.	PKN	MBK	0,1003	0,1476
Portfolio 12.	PKN	OPL	0,0614	0,0684
Portfolio 13.	PKN	PEO	0,1148	0,1167
Portfolio 14.	PKN	PGE	0,0978	0,1405
Portfolio 15.	PKN	PKO	0,1077	0,0965
Portfolio 16.	PKN	PZU	0,0858	0,0919
Portfolio 17.	PKN	SPL	0,1049	0,1050

Source: Bielska (2023).

In the vast majority of cases (15 out of 17 portfolios), the construction of a two-component portfolio by including PKN Orlen in the portfolio reduced the risk of the investment. Only in the case of Asseco Poland S.A. and PKO BP Bank Polski S.A. did the risk of a two-component portfolio increase compared with the risk achieved by individual companies. The risk of an investment involving a monthly adjustment of the portfolio was also examined according to the assumption that the investor chooses the binary portfolio that for a given month achieves the lowest minimum risk among the analysed portfolios.

Table 4 shows the monthly adjustments to the composition and shares of the companies in the MVP, so as to invest in the portfolio with the lowest minimum risk among the two-component portfolios analysed, as recommended. The monthly return of this portfolio was also determined. The standard deviation of the returns of the portfolio constructed in this way was 0.0658. Comparing this result with the data in Table 3, we can conclude that the investment strategy of adjusting the composition and/or shares of the companies in the two-component portfolio on a monthly basis proved to be effective in terms of risk. Risk measures were presented in figure 2.

Table 4.

Composition of two-component portfolios for the month based on recommended shares in the portfolio with the lowest MVP among the portfolios analysed

month	I company in the portfolio	II company in the portfolio	PKN Orlen's share	II company share	portfolio return for the recommended shares
III 2023	PKN	ACP	-3%	103%	-0,0464
II 2023	PKN	ACP	7%	93%	0,0363
I 2023	PKN	ACP	5%	95%	0,0472
XII 2022	PKN	ACP	4%	96%	-0,0095
XI 2022	PKN	ACP	10%	90%	0,0651
X 2022	PKN	OPL	36%	64%	0,1111
IX 2022	PKN	OPL	32%	68%	-0,1297
VIII 2022	PKN	OPL	43%	57%	-0,0860
VII 2022	PKN	OPL	54%	46%	0,0430
VI 2022	PKN	OPL	55%	45%	-0,0440
V 2022	PKN	KTY	16%	84%	-0,0343
IV 2022	PKN	OPL	35%	65%	-0,1005
III 2022	PKN	OPL	35%	65%	0,0322
II 2022	PKN	OPL	36%	64%	-0,0191
I 2022	PKN	OPL	33%	67%	-0,0714

Cont. table 4.

XII 2021	PKN	OPL	33%	67%	-0,0012
XI 2021	PKN	ACP	7%	93%	-0,1194
X 2021	PKN	ACP	-4%	104%	0,1358
IX 2021	PKN	ACP	-5%	105%	0,0332
VIII 2021	PKN	ACP	1%	99%	0,0445
VII 2021	PKN	ACP	-3%	103%	0,0439
VI 2021	PKN	ACP	-4%	104%	0,0509
V 2021	PKN	ACP	-1%	101%	0,0387
IV 2021	PKN	CPS	-2%	102%	-0,0022
III 2021	PKN	CPS	-2%	102%	0,0308
II 2021	PKN	CPS	-11%	111%	-0,0757
I 2021	PKN	CPS	-12%	112%	0,0147

Source: Bielska (2023).

The recommended portfolio is the one in which there was a monthly adjustment of the composition and share of companies in the portfolio. The purple color represents the standard deviation of this portfolio's returns, while the yellow color represents the standard deviation of PKN Orlen's returns

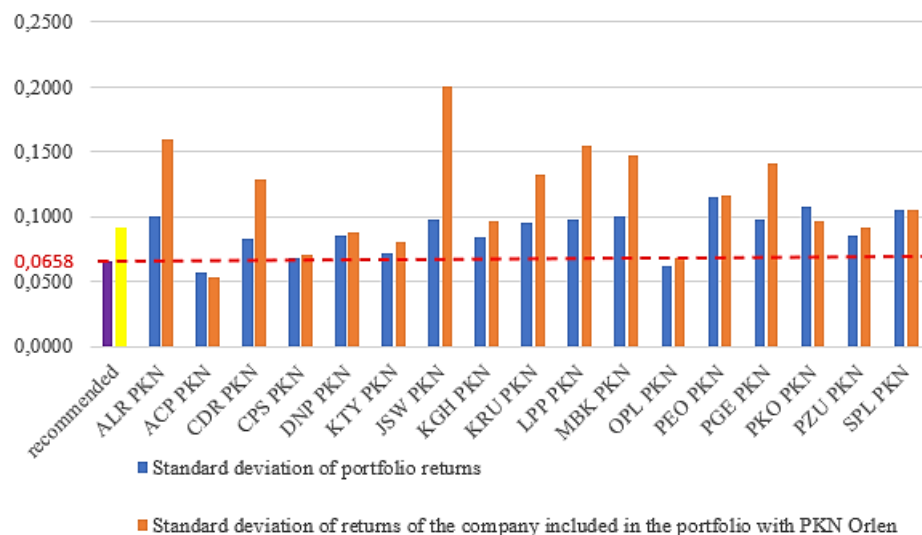


Figure 2. Standard deviations of the returns of the analysed two-component portfolios and the recommended portfolio with monthly adjustments to the composition and/or holdings of the portfolio companies.

Source: Bielska (2023).

Investing for the entire period in a given two-component portfolio out of the 17 portfolios analysed would have given a better result only in the case of two portfolios composed of shares of PKN Orlen and Asseco and PKN Orlen and Orange. In the case of 15 portfolios, maintaining a constant composition of companies in the portfolio would give a worse result in terms of risk than a strategy of monthly selection of the composition and/or shares of companies in the portfolio (Figure 2.).

Discussion

The research carried out showed that Markowitz's portfolio theory in the sense of MVP construction leads to a reduction in investment risk. In the vast majority of cases, two-component portfolios performed better in terms of risk than the individual companies included in these portfolios. In addition to the selection of appropriate shares of companies in the portfolio, the diversification of the portfolio itself as a result of increasing the number of portfolio companies is also important here. In the study, a simulation was carried out using the strategy of selecting for each month of the period January 2021 - March 2023 the portfolio with the lowest MVP among the portfolios analysed. This therefore represents a proposed solution to the dilemma of which portfolio an investor should opt for. The risk, as measured by the standard deviation of returns from such a strategy, turned out to be one of the lowest compared to the strategy of continuous investment in one of the 17 portfolios analysed. Only in the case of continuous investment in binary portfolios composed of shares of PKN Orlen and Asseco and PKN Orlen and Orange would better results be achieved in terms of minimising investment risk.

In this paper, the analysis was performed on a limited number of companies. In addition, the portfolios analysed were limited to those containing PKN Orlen. Two companies that were not listed in the WIG20 index for the entire period under study were excluded from the analysis. By constructing two-component portfolios, we would obtain 190 portfolios from all companies included in the WIG20 index. The subject of the analysis was therefore only 8.9% of all possible portfolios. Extending the analysis to multi-component portfolios to a greater extent than was done in this study could provide interesting conclusions. Risk minimisation is also related to the procedure of selecting companies for the portfolio itself. Additional correlations can be used here, such as industry affiliation, company-specific risk, values of financial ratios, company ratings, etc.

The analysis covered a limited period of time and was carried out on a monthly rate basis, which still posed a huge analytical challenge. Recent years have been a period of high uncertainty in the financial markets and in the global economy which needs to be taken into account. An analysis taking into account bull and bear market periods would most likely have provided additional insights in terms of adjusting investment risk minimisation strategies. Similarly, shortening the interval to weekly or daily data could inspire further research.

It is also worth noting the different attitudes of investors towards risk (risk aversion), psychological factors (e.g. emotions), experience and the purpose of investing (securing capital or seeking above-average returns).

Conclusion

Several researchers have analyzed the stability of the risk minimization approach for some risk measures (Cesarone et al., 2020). The results obtained confirm the usefulness of Markowitz's theory in minimising investment risk and therefore do not allow the research hypothesis to be rejected.

The simulation carried out was of an exemplary nature, concerned a limited period and analysed a limited number of companies, additionally assuming the presence of one of them in all analysed two-component portfolios. The proposed approach based on the selection of the portfolio with the lowest minimum risk proved to be successful and can be further tested in other periods and on a different set of portfolio companies.

In further research, it makes sense to analyse risk in relation to the rate of return. There is a distinct lack of studies on the stability of portfolio theory in terms of portfolio diversification or the optimisation of the risk-return ratio.

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Appendix

Essential calculations and simulation results (tables A1-A14).

Table A1.

Monthly returns of companies included in the WIG20 index, part 1/2

	PKN	ALR	ACP	CDR	CPS	DNP	KTY	JSW	KGH
III 2023	-0,1263	-0,0526	-0,0488	-0,1691	-0,0379	0,0457	0,0600	-0,1435	-0,0567
II 2023	0,0265	0,0360	0,0370	-0,0509	-0,0574	-0,0520	-0,0050	-0,1842	-0,0965
I 2023	0,0106	0,1436	0,0489	0,0800	0,0420	0,0421	0,0813	0,1573	0,1097
XII 2022	-0,0237	-0,0611	-0,0089	-0,0253	-0,0673	0,0209	-0,2306	-0,0607	0,0580
XI 2022	0,1686	0,2265	0,0541	0,0273	0,0328	0,1549	0,1891	0,4399	0,1923
X 2022	0,0258	0,2755	-0,0036	0,2710	0,1049	0,0473	0,0207	0,2456	0,1046
IX 2022	-0,1162	-0,1028	-0,0369	0,1929	-0,1769	-0,1118	-0,1257	-0,2966	0,0018
VIII 2022	-0,1923	0,0399	-0,0138	-0,0580	-0,0339	-0,0506	0,0055	-0,0656	-0,2334
VII 2022	0,1106	-0,0820	-0,0431	-0,0481	-0,0575	0,1343	-0,0939	-0,1994	-0,0158
VI 2022	-0,0728	-0,1812	-0,0308	-0,1246	-0,0693	0,0777	-0,0226	-0,0354	-0,1800
V 2022	-0,0186	-0,0749	-0,0109	-0,0931	-0,0915	0,0382	-0,0374	-0,0048	0,0243
IV 2022	-0,0182	-0,1980	-0,0430	-0,3047	-0,1325	-0,1526	0,0525	-0,1320	-0,1621
III 2022	0,0677	-0,0148	0,0768	0,0220	0,0168	0,1426	0,0557	0,4407	0,0384
II 2022	-0,0062	-0,1706	-0,1009	-0,0711	-0,1435	-0,0629	-0,0574	0,2305	0,1713
I 2022	-0,0470	0,0159	-0,0607	-0,0665	-0,1017	-0,1467	-0,0210	0,1268	-0,0085
XII 2021	0,0178	-0,0595	-0,0159	0,0510	-0,0057	0,0803	0,0517	-0,1648	-0,0313
XI 2021	-0,1648	-0,0932	-0,1162	0,0372	-0,0223	-0,0537	-0,0750	-0,1941	-0,0659
X 2021	0,0591	0,4846	0,1326	-0,0872	0,0045	0,0774	-0,0063	-0,0582	-0,0167
IX 2021	0,1009	-0,0227	0,0367	0,1216	-0,0332	0,0253	-0,0378	0,3797	-0,1093
VIII 2021	0,0068	0,1810	0,0448	-0,0772	0,0690	0,0529	-0,0541	0,1526	-0,0891
VII 2021	-0,0525	0,1077	0,0416	-0,0019	0,1274	0,0909	0,0611	-0,0114	0,0351
VI 2021	-0,0614	-0,0122	0,0468	0,1851	-0,0235	-0,0241	0,0384	-0,0377	-0,0733
V 2021	0,2176	0,1922	0,0405	-0,0370	0,0417	0,1476	0,0113	0,1999	0,0254
IV 2021	0,0507	0,2065	0,0376	-0,0874	-0,0014	-0,0664	0,0924	0,0236	0,0242
III 2021	0,0577	0,0097	0,0090	-0,1976	0,0314	0,0399	0,0769	-0,1847	-0,0158
II 2021	0,0414	0,2759	-0,0206	-0,2255	-0,0641	-0,0786	0,0873	0,0926	-0,0388
I 2021	-0,0495	0,0074	-0,0044	0,1038	0,0079	-0,1000	-0,0264	0,2174	0,0134
XII 2020	0,0126	0,0217	0,0303	-0,2999	0,1470	0,1457	0,0685	0,0380	0,2208
XI 2020	0,4367	0,4457	0,0263	0,1336	0,0801	0,1527	0,1308	0,5838	0,2616
X 2020	-0,1775	-0,1554	-0,0777	-0,1955	-0,0960	-0,0589	-0,1028	-0,4180	-0,0030
IX 2020	-0,0985	-0,0240	-0,0225	-0,0458	-0,0519	0,0170	-0,0387	0,6332	-0,1449
VIII 2020	-0,0542	-0,0680	0,1094	0,0963	0,0375	0,0699	0,1002	-0,0762	0,0793
VII 2020	-0,1543	-0,0975	-0,0347	0,0164	0,0626	0,0484	-0,0159	-0,1226	0,3919
VI 2020	-0,0764	0,1062	-0,1081	-0,0249	0,0000	0,0926	0,2659	0,1000	0,0294
V 2020	0,0919	-0,0269	0,0912	0,1504	0,0124	0,0735	-0,0725	0,2442	0,1504
IV 2020	0,1548	0,1792	0,1554	0,2614	0,0785	0,1121	0,1498	0,1408	0,3047
III 2020	-0,0943	-0,4161	-0,0397	0,0042	-0,0518	0,1057	-0,0982	-0,1421	-0,1916
II 2020	-0,2231	-0,2170	-0,0486	-0,0075	-0,0728	-0,1220	0,0028	-0,2803	-0,2316
I 2020	-0,1253	-0,0784	0,0071	-0,0014	-0,0272	0,1261	0,0585	-0,1400	-0,0555

Source: Bielska (2023).

Table A2.*Monthly returns of companies included in the WIG20 index, part 2/2*

	KRU	LPP	MBK	OPL	PEO	PGE	PKO	PZU	SPL
III 2023	-0,0717	0,0191	-0,0613	0,0113	-0,0542	-0,0688	-0,0906	-0,0428	-0,0162
II 2023	-0,0575	-0,0645	0,0250	-0,0394	-0,0273	-0,1093	-0,0348	-0,0049	0,0411
I 2023	0,1233	-0,0498	0,0736	0,0474	0,0598	0,0874	0,0544	0,0373	0,1133
XII 2022	0,0368	0,0985	-0,0773	0,0276	0,0049	0,0494	0,0517	0,1121	-0,0567
XI 2022	0,0688	0,1428	0,1674	0,0446	0,0688	0,1658	0,0816	0,1747	0,0688
X 2022	0,1847	0,0375	0,3407	0,1587	0,2944	-0,1382	0,1992	0,1507	0,2930
IX 2022	-0,2165	-0,0835	-0,0600	-0,1360	-0,0662	-0,1161	-0,0667	-0,1729	-0,0738
VIII 2022	0,1284	-0,1480	-0,0269	-0,0043	-0,1141	-0,3064	-0,1104	-0,0709	-0,0877
VII 2022	0,0923	0,1107	-0,0178	-0,0369	-0,0999	-0,0291	-0,0643	0,0100	-0,0101
VI 2022	-0,1263	-0,1343	-0,1938	-0,0095	-0,1272	0,0591	-0,1269	-0,0747	-0,0754
V 2022	0,0646	0,0840	-0,0720	-0,0778	-0,0466	0,0311	-0,0242	0,0510	-0,0459
IV 2022	-0,1827	-0,1941	-0,1596	-0,1447	-0,1362	0,0637	-0,1848	-0,0971	-0,1248
III 2022	0,1917	0,3214	-0,1385	0,0128	-0,0204	0,1130	-0,0126	0,0581	-0,0139
II 2022	-0,1994	-0,4557	-0,1156	-0,0263	-0,1500	0,0595	-0,1633	-0,1357	-0,1187
I 2022	0,0086	-0,0788	0,0680	-0,0835	0,1070	-0,0567	0,0549	0,0226	0,0003
XII 2021	-0,0382	0,2845	-0,1181	-0,0105	0,0167	-0,0289	0,0218	-0,0194	-0,0271
XI 2021	0,0126	-0,0643	-0,1461	0,0963	-0,1041	-0,1669	-0,1112	-0,0992	-0,0342
X 2021	0,0413	-0,0198	0,3911	-0,0305	0,2917	0,1070	0,1614	0,0986	0,2236
IX 2021	0,0150	0,0678	0,0960	-0,0302	-0,0401	-0,1141	0,0045	-0,1010	-0,0060
VIII 2021	0,0306	0,0050	0,1493	0,0767	0,1296	0,1571	0,1037	0,0772	0,1774
VII 2021	0,1901	0,0646	-0,0214	0,1323	0,0114	-0,0815	-0,0047	0,0242	0,0027
VI 2021	-0,0226	0,1430	0,0691	0,0037	-0,0310	-0,0590	-0,0675	-0,0097	-0,0472
V 2021	0,3991	0,1336	0,2868	-0,0177	0,1929	-0,0132	0,1463	0,1333	0,1914
IV 2021	-0,0066	0,2114	0,0930	0,0389	0,1273	0,4853	0,0688	-0,0447	0,0313
III 2021	0,0011	0,0227	-0,0360	0,0428	0,0247	0,0116	0,0766	0,1458	0,0311
II 2021	0,0945	0,0222	0,1124	-0,0344	0,0594	0,0039	0,0498	-0,0227	0,1592
I 2021	0,1782	-0,0953	0,0867	-0,0091	0,0617	-0,0085	0,0056	-0,0782	-0,0273
XII 2020	-0,0173	0,2060	0,1728	0,0427	0,0682	0,1246	0,0769	0,2665	0,0672
XI 2020	0,2285	0,3314	0,2940	0,0377	0,3347	0,2316	0,3764	0,1486	0,4066
X 2020	-0,1372	-0,2120	-0,3178	-0,1131	-0,1659	-0,3010	-0,1163	-0,1346	-0,1488
IX 2020	-0,1253	-0,0869	-0,1102	-0,0624	-0,0448	0,0700	-0,0226	-0,0929	-0,0649
VIII 2020	0,1329	0,0338	-0,0084	0,0299	0,0336	-0,0939	-0,0115	0,0026	0,0066
VII 2020	0,1906	0,1405	-0,1831	0,1402	-0,0605	-0,0425	-0,0469	-0,0699	-0,1406
VI 2020	0,0599	-0,1220	0,0550	-0,0496	0,0094	0,4164	0,0128	-0,0357	0,0566
V 2020	0,2831	0,0719	-0,0209	-0,0461	0,0306	0,1911	0,0281	0,0013	0,0194
IV 2020	0,2052	0,2683	0,0018	0,1995	-0,0583	0,1051	-0,0174	-0,0232	-0,0417
III 2020	-0,5254	-0,2571	-0,2704	-0,0668	-0,3755	-0,1900	-0,3003	-0,1197	-0,3337
II 2020	-0,1534	-0,1878	-0,1989	-0,1248	-0,1053	-0,3559	-0,0797	-0,1321	-0,1218
I 2020	-0,0233	-0,0315	-0,0358	-0,0162	-0,0258	-0,1425	-0,0198	-0,0064	-0,0641

Source: Bielska (2023).

Table A3.

Correlation coefficients of monthly returns of PKN Orlen with other companies under study, part 1/2

	ALR	ACP	CDR	CPS	DNP	KTY	JSW	KGH
III 2023	0,3831	0,4830	0,0797	0,4564	0,6637	0,4059	0,5359	0,6703
II 2023	0,3613	0,3885	0,0884	0,4360	0,6848	0,4036	0,5707	0,6553
I 2023	0,3493	0,4129	0,0901	0,4553	0,6626	0,4021	0,5522	0,6593
XII 2022	0,3401	0,4171	0,1002	0,4601	0,6664	0,4874	0,5082	0,6651
XI 2022	0,0932	0,3913	-0,0002	0,2372	0,5810	0,2508	0,3930	0,5275
X 2022	0,2274	0,4644	-0,1895	0,2303	0,5974	0,2309	0,3173	0,4905
IX 2022	0,1936	0,5074	0,1826	0,1342	0,5340	0,0307	0,3738	0,4389
VIII 2022	0,3169	0,6183	0,2108	0,2244	0,5325	0,1290	0,3668	0,1826
VII 2022	0,3593	0,6991	0,1952	0,0974	0,3758	0,2843	0,6228	0,1213
VI 2022	0,3036	0,6239	-0,0031	0,0545	0,4692	0,1956	0,6239	0,0300
V 2022	0,3941	0,5475	-0,0388	0,1902	0,5964	0,1816	0,5731	0,1487
IV 2022	0,4042	0,5478	-0,1839	0,1681	0,5739	0,2500	0,5564	0,1322
III 2022	0,4183	0,5242	-0,2439	0,1728	0,5666	0,2486	0,4588	0,0998
II 2022	0,4314	0,5388	-0,2597	0,1291	0,5131	0,2498	0,5160	0,2403
I 2022	0,4341	0,5173	-0,3352	0,0189	0,5248	0,2556	0,4621	0,2026
XII 2021	0,4517	0,5251	-0,2755	0,0037	0,4753	0,2466	0,4925	0,0974
XI 2021	0,5691	0,0083	0,1850	0,1052	0,5369	0,3802	0,7056	0,5426
X 2021	0,7831	0,3963	0,2886	0,3122	0,5968	0,5457	0,7896	0,5128
IX 2021	0,8497	0,4320	0,2525	0,4013	0,5889	0,6371	0,4991	0,6285
VIII 2021	0,8660	0,2612	0,1926	0,4012	0,5609	0,5913	0,5163	0,6080
VII 2021	0,8948	0,3618	0,1575	0,4233	0,5537	0,6406	0,5388	0,2142
VI 2021	0,8687	0,4302	0,2371	0,4139	0,4891	0,3435	0,5207	0,1938
V 2021	0,8224	0,4120	0,2770	0,3939	0,4203	0,3329	0,5308	0,2663
IV 2021	0,8425	0,4715	0,3711	0,4449	0,5166	0,3770	0,5312	0,3519
III 2021	0,7683	0,4931	0,4104	0,4694	0,4609	0,4084	0,6029	0,4170
II 2021	0,8185	0,5399	0,4712	0,5903	0,6337	0,4029	0,6558	0,5370
I 2021	0,8208	0,5309	0,4852	0,6013	0,6279	0,3831	0,6812	0,5504

Source: Bielska (2023).

Table A4.

Correlation coefficients of monthly returns of PKN Orlen with other companies under study, part 2/2

	KRU	LPP	MBK	OPL	PEO	PGE	PKO	PZU	SPL
III 2023	0,3438	0,6582	0,3695	0,3161	0,3784	0,6421	0,4547	0,6834	0,4474
II 2023	0,3330	0,5038	0,3587	0,3282	0,3650	0,6792	0,4294	0,6403	0,4242
I 2023	0,3268	0,5118	0,3242	0,3417	0,3034	0,6881	0,3860	0,6268	0,4209
XII 2022	0,3228	0,5127	0,3003	0,3599	0,3128	0,6967	0,4135	0,6680	0,4156
XI 2022	0,2407	0,4546	0,1779	0,0149	0,2788	0,6545	0,3409	0,5580	0,3193
X 2022	0,2060	0,4301	0,2700	-0,1465	0,3559	0,7715	0,4054	0,6120	0,4200
IX 2022	0,0944	0,4406	0,3433	-0,3106	0,3208	0,5935	0,4350	0,3901	0,3964
VIII 2022	0,3813	0,4138	0,4199	-0,2489	0,2489	0,2774	0,3735	0,3447	0,2952
VII 2022	0,1711	0,3505	0,4554	-0,3015	0,3680	0,4154	0,4504	0,2945	0,3270
VI 2022	0,1076	0,2558	0,3581	-0,3163	0,3222	0,5025	0,4194	0,2403	0,3070
V 2022	0,5360	0,3077	0,5383	-0,2944	0,4865	0,3469	0,5653	0,4982	0,5168
IV 2022	0,5288	0,3119	0,5439	-0,4137	0,4988	0,3067	0,6100	0,4680	0,5205
III 2022	0,4908	0,2655	0,6098	-0,3923	0,5262	0,2828	0,6464	0,4584	0,5491
II 2022	0,5362	0,3467	0,6265	-0,4219	0,5639	0,2853	0,7538	0,4682	0,5751
I 2022	0,4355	0,3524	0,6179	-0,5595	0,5929	0,2699	0,7867	0,5186	0,5831
XII 2021	0,4445	0,3899	0,6642	-0,5685	0,5973	0,2644	0,7785	0,3850	0,6028
XI 2021	0,5012	0,6222	0,5684	-0,1577	0,6997	0,2818	0,8898	0,3458	0,8093
X 2021	0,6090	0,7329	0,7664	0,1743	0,8593	0,4587	0,9337	0,4806	0,8838
IX 2021	0,6636	0,7583	0,7854	0,2759	0,9288	0,4769	0,9641	0,5915	0,9243
VIII 2021	0,6323	0,7577	0,8066	0,2840	0,9463	0,5092	0,9781	0,6032	0,9635
VII 2021	0,5661	0,6729	0,8251	0,1475	0,9495	0,5057	0,9747	0,6351	0,9674
VI 2021	0,5529	0,7174	0,8250	0,1831	0,9482	0,3364	0,9799	0,6408	0,9487
V 2021	0,4620	0,7143	0,7705	0,1930	0,9233	0,4300	0,9674	0,5885	0,9270
IV 2021	0,5239	0,7499	0,7408	0,3064	0,8189	0,4685	0,8883	0,5617	0,8490
III 2021	0,4717	0,7417	0,7428	0,3321	0,7069	0,5043	0,7958	0,5926	0,7889
II 2021	0,5124	0,7718	0,7690	0,4390	0,7064	0,5935	0,7864	0,6363	0,8001
I 2021	0,5349	0,7734	0,7845	0,4392	0,7128	0,6067	0,7808	0,6220	0,7982

Source: Bielska (2023).

Table A5.*Standard deviations of monthly returns of the surveyed companies, part 1/2*

	PKN	ALR	ACP	CDR	CPS	DNP	KTY	JSW	KGH
III 2023	0,0929	0,1442	0,0397	0,1424	0,0755	0,0950	0,1030	0,2334	0,1245
II 2023	0,0925	0,1511	0,0472	0,1430	0,0807	0,0958	0,1039	0,2304	0,1314
I 2023	0,0931	0,1438	0,0456	0,1409	0,0770	0,1063	0,0999	0,2295	0,1279
XII 2022	0,0933	0,1438	0,0456	0,1424	0,0784	0,1082	0,0791	0,2357	0,1268
XI 2022	0,0863	0,1223	0,0471	0,1427	0,0747	0,1004	0,0576	0,2120	0,1120
X 2022	0,0887	0,1725	0,0656	0,1141	0,0599	0,1020	0,0564	0,1983	0,1047
IX 2022	0,0917	0,1714	0,0673	0,1028	0,0506	0,0967	0,0476	0,2101	0,1055
VIII 2022	0,0742	0,1804	0,0694	0,1031	0,0612	0,0956	0,0483	0,2108	0,0910
VII 2022	0,0679	0,1824	0,0701	0,1040	0,0777	0,0919	0,0476	0,1987	0,0931
VI 2022	0,0671	0,1743	0,0708	0,1195	0,0769	0,0903	0,0490	0,1988	0,0832
V 2022	0,0918	0,1788	0,0714	0,1178	0,0765	0,0983	0,0479	0,2012	0,0832
IV 2022	0,0920	0,1698	0,0702	0,0844	0,0681	0,0884	0,0525	0,1921	0,0727
III 2022	0,0915	0,1689	0,0676	0,0999	0,0687	0,0810	0,0545	0,1740	0,0713
II 2022	0,0916	0,1608	0,0600	0,1146	0,0580	0,0823	0,0550	0,1653	0,0448
I 2022	0,0917	0,1612	0,0560	0,1199	0,0489	0,0756	0,0554	0,1716	0,0461
XII 2021	0,0917	0,1557	0,0551	0,1405	0,0612	0,0821	0,0564	0,1608	0,0829
XI 2021	0,1331	0,1670	0,0357	0,1477	0,0613	0,0861	0,0563	0,2006	0,1090
X 2021	0,1495	0,1561	0,0351	0,1535	0,0707	0,0891	0,0676	0,2461	0,1086
IX 2021	0,1538	0,1562	0,0362	0,1448	0,0721	0,0892	0,0677	0,2791	0,1126
VIII 2021	0,1555	0,1611	0,0445	0,1511	0,0709	0,0897	0,0654	0,2831	0,1088
VII 2021	0,1622	0,1684	0,0461	0,1517	0,0647	0,0880	0,0669	0,2880	0,1475
VI 2021	0,1629	0,1670	0,0552	0,1352	0,0639	0,0885	0,0925	0,2859	0,1423
V 2021	0,1535	0,1653	0,0600	0,1476	0,0634	0,0828	0,0984	0,2876	0,1432
IV 2021	0,1586	0,1634	0,0731	0,1697	0,0656	0,0805	0,1018	0,2870	0,1545
III 2021	0,1607	0,2094	0,0745	0,1609	0,0684	0,0823	0,1095	0,2836	0,1724
II 2021	0,1717	0,2036	0,0758	0,1463	0,0693	0,0886	0,1087	0,3033	0,1916
I 2021	0,1740	0,2040	0,0757	0,1440	0,0702	0,0793	0,1076	0,3056	0,1943

Source: Bielska (2023).

Table A6.*Standard deviations of monthly returns of the surveyed companies, part 2/2*

	KRU	LPP	MBK	OPL	PEO	PGE	PKO	PZU	SPL
III 2023	0,1332	0,1426	0,1433	0,0800	0,1143	0,1280	0,1001	0,1003	0,1099
II 2023	0,1458	0,1921	0,1456	0,0797	0,1201	0,1257	0,1077	0,1086	0,1140
I 2023	0,1420	0,1926	0,1453	0,0798	0,1236	0,1239	0,1078	0,1083	0,1079
XII 2022	0,1421	0,2087	0,1470	0,0785	0,1239	0,1228	0,1062	0,1031	0,1074
XI 2022	0,1406	0,2039	0,1376	0,0835	0,1224	0,1161	0,1021	0,0894	0,1042
X 2022	0,1295	0,2030	0,1498	0,0634	0,1218	0,1191	0,0947	0,0814	0,0867
IX 2022	0,1150	0,2041	0,1550	0,0560	0,1215	0,1190	0,0958	0,0733	0,0861
VIII 2022	0,1089	0,2004	0,1633	0,0630	0,1269	0,0929	0,1020	0,0777	0,1004
VII 2022	0,1193	0,1985	0,1633	0,0757	0,1244	0,0961	0,1016	0,0782	0,1004
VI 2022	0,1134	0,1989	0,1562	0,0758	0,1193	0,0968	0,0978	0,0762	0,0990
V 2022	0,1565	0,2008	0,1730	0,0728	0,1291	0,0965	0,1078	0,0847	0,1110
IV 2022	0,1428	0,1965	0,1637	0,0592	0,1225	0,1658	0,0943	0,0811	0,1023
III 2022	0,1369	0,1787	0,1561	0,0598	0,1211	0,1641	0,0952	0,0895	0,1014
II 2022	0,1175	0,1050	0,1472	0,0603	0,1054	0,1638	0,0767	0,0792	0,0951
I 2022	0,1205	0,1069	0,1472	0,0532	0,1046	0,1625	0,0772	0,0834	0,0968
XII 2021	0,1190	0,0950	0,1361	0,0526	0,1038	0,1638	0,0777	0,1089	0,0934
XI 2021	0,1243	0,1137	0,1222	0,0484	0,1142	0,1594	0,1082	0,1054	0,1279
X 2021	0,1395	0,1389	0,1543	0,0598	0,1209	0,1888	0,1183	0,1162	0,1390
IX 2021	0,1499	0,1460	0,1630	0,0623	0,1212	0,1833	0,1195	0,1155	0,1426
VIII 2021	0,1504	0,1452	0,1620	0,0595	0,1198	0,1844	0,1201	0,1150	0,1392
VII 2021	0,1505	0,1468	0,1738	0,0610	0,1236	0,1827	0,1222	0,1182	0,1486
VI 2021	0,1476	0,1540	0,1737	0,0630	0,1219	0,2081	0,1180	0,1189	0,1463
V 2021	0,1293	0,1521	0,1568	0,0643	0,1144	0,2086	0,1145	0,1138	0,1398
IV 2021	0,1316	0,1580	0,1549	0,0843	0,1141	0,1719	0,1153	0,1131	0,1413
III 2021	0,2154	0,1793	0,1724	0,0867	0,1589	0,1851	0,1466	0,1101	0,1729
II 2021	0,2217	0,1887	0,1746	0,0935	0,1595	0,2155	0,1475	0,1149	0,1682
I 2021	0,2171	0,1866	0,1703	0,0936	0,1574	0,2197	0,1475	0,1137	0,1686

Source: Bielska (2023).

Table A7.*Shares of companies in two-component portfolios with minimal risk (portfolio 1-9)*

	Portfolio 1		Portfolio 2		Portfolio 3		Portfolio 4		Portfolio 5		Portfolio 6		Portfolio 7		Portfolio 8		Portfolio 9	
	PKN	ALR	PKN	ACP	PKN	CDR	PKN	CPS	PKN	DNP	PKN	KTY	PKN	JSW	PKN	KGH	PKN	KRU
III 2023	0,18	0,82	1,03	-0,03	0,28	0,72	0,68	0,32	0,47	0,53	0,41	0,59	-0,07	1,07	0,10	0,90	0,25	0,75
II 2023	0,16	0,84	0,93	0,07	0,28	0,72	0,62	0,38	0,45	0,55	0,40	0,60	-0,10	1,10	0,06	0,94	0,20	0,80
I 2023	0,20	0,80	0,95	0,05	0,29	0,71	0,67	0,33	0,31	0,69	0,44	0,56	-0,08	1,08	0,09	0,91	0,22	0,78
XII 2022	0,20	0,80	0,96	0,04	0,28	0,72	0,66	0,34	0,28	0,72	0,66	0,34	-0,06	1,06	0,09	0,91	0,22	0,78
XI 2022	0,32	0,68	0,90	0,10	0,27	0,73	0,59	0,41	0,32	0,68	0,75	0,25	0,01	0,99	0,24	0,76	0,21	0,79
X 2022	0,14	0,86	0,76	0,24	0,40	0,60	0,74	0,26	0,33	0,67	0,77	0,23	0,06	0,94	0,34	0,66	0,28	0,72
IX 2022	0,17	0,83	0,79	0,21	0,43	0,57	0,80	0,20	0,44	0,56	0,79	0,21	0,03	0,97	0,38	0,62	0,38	0,62
VIII 2022	0,04	0,96	0,59	0,41	0,30	0,70	0,62	0,38	0,24	0,76	0,73	0,27	-0,01	1,01	0,38	0,62	0,22	0,78
VII 2022	0,01	0,99	0,45	0,55	0,26	0,74	0,43	0,57	0,27	0,73	0,73	0,27	-0,14	1,14	0,33	0,67	0,20	0,80
VI 2022	0,03	0,97	0,43	0,57	0,24	0,76	0,43	0,57	0,24	0,76	0,69	0,31	-0,14	1,14	0,39	0,61	0,23	0,77
V 2022	0,07	0,93	0,76	0,24	0,38	0,62	0,61	0,39	0,42	0,58	0,84	0,16	-0,08	1,08	0,56	0,44	0,04	0,96
IV 2022	0,09	0,91	0,78	0,22	0,54	0,46	0,67	0,33	0,55	0,45	0,82	0,18	-0,05	1,05	0,63	0,37	0,10	0,90
III 2022	0,08	0,92	0,79	0,21	0,47	0,53	0,67	0,33	0,64	0,36	0,80	0,20	0,04	0,96	0,64	0,36	0,15	0,85
II 2022	0,09	0,91	0,89	0,11	0,41	0,59	0,74	0,26	0,61	0,39	0,80	0,20	0,03	0,97	0,88	0,12	0,25	0,75
I 2022	0,09	0,91	0,92	0,08	0,40	0,60	0,78	0,22	0,70	0,30	0,80	0,20	0,05	0,95	0,86	0,14	0,27	0,73
XII 2021	0,10	0,90	0,94	0,06	0,34	0,66	0,69	0,31	0,61	0,39	0,79	0,21	0,06	0,94	0,56	0,44	0,28	0,72
XI 2021	0,25	0,75	0,93	0,07	0,44	0,56	0,85	0,15	0,90	0,10	0,98	0,02	-0,06	1,06	0,71	0,29	0,57	0,43
X 2021	0,40	0,60	1,04	-0,04	0,48	0,52	0,92	0,08	1,00	0,00	1,06	-0,06	-0,27	1,27	0,80	0,20	0,59	0,41
IX 2021	0,45	0,55	1,05	-0,05	0,54	0,46	0,96	0,04	1,01	-0,01	1,14	-0,14	0,04	0,96	0,88	0,12	0,54	0,46
VIII 2021	0,37	0,63	0,99	0,01	0,52	0,48	0,97	0,03	0,99	0,01	1,11	-0,11	0,02	0,98	0,90	0,10	0,55	0,45
VII 2021	0,32	0,68	1,03	-0,03	0,54	0,46	1,01	-0,01	1,01	-0,01	1,15	-0,15	0,02	0,98	0,56	0,44	0,59	0,41
VI 2021	0,41	0,59	1,04	-0,04	0,62	0,38	1,01	-0,01	0,96	0,04	0,86	0,14	0,04	0,96	0,58	0,42	0,61	0,39
V 2021	0,29	0,71	1,01	-0,01	0,53	0,47	0,99	0,01	0,92	0,08	0,80	0,20	0,00	1,00	0,55	0,45	0,66	0,34
IV 2021	0,40	0,60	1,01	-0,01	0,45	0,55	1,02	-0,02	1,01	-0,01	0,82	0,18	0,02	0,98	0,52	0,48	0,69	0,31
III 2021	0,00	1,00	1,02	-0,02	0,50	0,50	1,02	-0,02	0,97	0,03	0,80	0,20	-0,03	1,03	0,44	0,56	0,24	0,76
II 2021	0,06	0,94	1,06	-0,06	0,65	0,35	1,11	-0,11	1,10	-0,10	0,84	0,16	-0,09	1,09	0,38	0,62	0,25	0,75
I 2021	0,08	0,92	1,06	-0,06	0,68	0,32	1,12	-0,12	1,12	-0,12	0,84	0,16	-0,12	1,12	0,38	0,62	0,27	0,73

Source: Bielska (2023).

Table A8.*Shares of companies in two-component portfolios with minimal risk (portfolio 10-17)*

	Portfolio 10		Portfolio 11		Portfolio 12		Portfolio 13		Portfolio 14		Portfolio 15		Portfolio 16		Portfolio 17	
	PKN	LPP	PKN	MBK	PKN	OPL	PKN	PEO	PKN	PGE	PKN	PKO	PKN	PZU	PKN	SPL
III 2023	-0,01	1,01	0,19	0,81	0,61	0,39	0,34	0,66	0,10	0,90	0,43	0,57	0,38	0,62	0,35	0,65
II 2023	-0,01	1,01	0,19	0,81	0,61	0,39	0,30	0,70	0,08	0,92	0,37	0,63	0,28	0,72	0,32	0,68
I 2023	-0,02	1,02	0,20	0,80	0,62	0,38	0,30	0,70	0,09	0,91	0,38	0,62	0,30	0,70	0,37	0,63
XII 2022	-0,04	1,04	0,21	0,79	0,63	0,37	0,30	0,70	0,09	0,91	0,39	0,61	0,35	0,65	0,38	0,62
XI 2022	-0,02	1,02	0,24	0,76	0,52	0,48	0,27	0,73	0,11	0,89	0,37	0,63	0,46	0,54	0,36	0,64
X 2022	0,00	1,00	0,18	0,82	0,64	0,36	0,27	0,73	-0,05	1,05	0,44	0,56	0,61	0,39	0,52	0,48
IX 2022	0,00	1,00	0,16	0,84	0,68	0,32	0,30	0,70	0,20	0,80	0,46	0,54	0,68	0,32	0,55	0,45
VIII 2022	-0,02	1,02	0,02	0,98	0,57	0,43	0,19	0,81	0,35	0,65	0,26	0,74	0,47	0,53	0,30	0,70
VII 2022	0,00	1,00	-0,02	1,02	0,46	0,54	0,11	0,89	0,23	0,77	0,17	0,83	0,40	0,60	0,23	0,77
VI 2022	0,03	0,97	0,04	0,96	0,45	0,55	0,14	0,86	0,17	0,83	0,20	0,80	0,42	0,58	0,24	0,76
V 2022	0,07	0,93	-0,01	1,01	0,59	0,41	0,20	0,80	0,46	0,54	0,32	0,68	0,58	0,42	0,31	0,69
IV 2022	0,08	0,92	0,01	0,99	0,65	0,35	0,23	0,77	0,14	0,86	0,47	0,53	0,62	0,38	0,39	0,61
III 2022	0,13	0,87	-0,02	1,02	0,65	0,35	0,22	0,78	0,15	0,85	0,44	0,56	0,52	0,48	0,39	0,61
II 2022	0,40	0,60	0,00	1,00	0,64	0,36	0,34	0,66	0,15	0,85	0,84	0,16	0,63	0,37	0,46	0,54
I 2022	0,38	0,62	0,01	0,99	0,67	0,33	0,34	0,66	0,16	0,84	0,88	0,12	0,60	0,40	0,44	0,56
XII 2021	0,47	0,53	0,01	0,99	0,67	0,33	0,35	0,65	0,16	0,84	0,85	0,15	0,36	0,64	0,48	0,52
XI 2021	0,70	0,30	0,60	0,40	0,85	0,15	0,75	0,25	0,38	0,62	1,29	-0,29	0,67	0,33	0,60	0,40
X 2021	0,64	0,36	0,43	0,57	0,91	0,09	1,15	-0,15	0,29	0,71	1,76	-0,76	0,73	0,27	0,81	0,19
IX 2021	0,61	0,39	0,37	0,63	0,94	0,06	1,71	-0,71	0,34	0,66	2,38	-1,38	0,82	0,18	0,98	0,02
VIII 2021	0,64	0,36	0,39	0,61	0,96	0,04	2,00	-1,00	0,33	0,67	2,85	-1,85	0,85	0,15	1,80	-0,80
VII 2021	0,65	0,35	0,31	0,69	0,92	0,08	2,07	-1,07	0,38	0,62	2,68	-1,68	0,89	0,11	1,71	-0,71
VI 2021	0,60	0,40	0,32	0,68	0,92	0,08	2,06	-1,06	0,32	0,68	2,76	-1,76	0,89	0,11	1,44	-0,44
V 2021	0,52	0,48	0,45	0,55	0,91	0,09	1,74	-0,74	0,25	0,75	2,46	-1,46	0,83	0,17	1,10	-0,10
IV 2021	0,51	0,49	0,55	0,45	0,87	0,13	1,21	-0,21	0,42	0,58	1,49	-0,49	0,85	0,15	0,87	0,13
III 2021	0,29	0,71	0,36	0,64	0,88	0,12	0,52	0,48	0,36	0,64	0,72	0,28	0,90	0,10	0,33	0,67
II 2021	0,30	0,70	0,46	0,54	0,93	0,07	0,62	0,38	0,23	0,77	0,84	0,16	0,96	0,04	0,55	0,45
I 2021	0,35	0,65	0,55	0,45	0,94	0,06	0,67	0,33	0,22	0,78	0,86	0,14	0,97	0,03	0,58	0,42

Source: Bielska (2023).

Table A9.*Minimal risk of two-component portfolios, part 1/2*

	PKN ALR	PKN ACP	PKN CDR	PKC CPS	PKN DNP	PKN KTY	PKN JSW	PKN KGH	PKN KRU
III 2023	0,0894	0,0396	0,0806	0,0701	0,0857	0,0817	0,0917	0,0925	0,0870
II 2023	0,0893	0,0468	0,0807	0,0726	0,0863	0,0817	0,0906	0,0923	0,0881
I 2023	0,0887	0,0455	0,0808	0,0711	0,0895	0,0806	0,0917	0,0927	0,0879
XII 2022	0,0886	0,0454	0,0815	0,0721	0,0902	0,0731	0,0925	0,0929	0,0880
XI 2022	0,0735	0,0464	0,0738	0,0627	0,0816	0,0529	0,0863	0,0830	0,0805
X 2022	0,0851	0,0626	0,0632	0,0545	0,0840	0,0521	0,0879	0,0821	0,0797
IX 2022	0,0866	0,0651	0,0744	0,0466	0,0823	0,0428	0,0915	0,0827	0,0749
VIII 2022	0,0739	0,0644	0,0658	0,0521	0,0713	0,0427	0,0742	0,0624	0,0706
VII 2022	0,0679	0,0635	0,0616	0,0536	0,0632	0,0437	0,0639	0,0579	0,0630
VI 2022	0,0669	0,0620	0,0585	0,0519	0,0641	0,0430	0,0630	0,0530	0,0604
V 2022	0,0910	0,0689	0,0710	0,0640	0,0846	0,0453	0,0908	0,0660	0,0916
IV 2022	0,0909	0,0680	0,0562	0,0589	0,0799	0,0499	0,0916	0,0606	0,0911
III 2022	0,0907	0,0655	0,0587	0,0592	0,0756	0,0513	0,0913	0,0589	0,0897
II 2022	0,0905	0,0595	0,0617	0,0517	0,0751	0,0517	0,0915	0,0434	0,0880
I 2022	0,0907	0,0557	0,0597	0,0435	0,0713	0,0521	0,0914	0,0441	0,0863
XII 2021	0,0907	0,0548	0,0660	0,0510	0,0741	0,0527	0,0914	0,0644	0,0862
XI 2021	0,1282	0,0345	0,1075	0,0577	0,0853	0,0562	0,1328	0,1035	0,1111
X 2021	0,1439	0,0346	0,1216	0,0697	0,0891	0,0672	0,1433	0,1054	0,1291
IX 2021	0,1490	0,0354	0,1180	0,0719	0,0892	0,0656	0,1535	0,1116	0,1384
VIII 2021	0,1525	0,0444	0,1184	0,0708	0,0897	0,0639	0,1554	0,1081	0,1381
VII 2021	0,1604	0,0459	0,1192	0,0647	0,0880	0,0641	0,1622	0,1202	0,1378
VI 2021	0,1592	0,0549	0,1154	0,0639	0,0884	0,0899	0,1626	0,1169	0,1359
V 2021	0,1509	0,0599	0,1202	0,0634	0,0821	0,0935	0,1535	0,1177	0,1188
IV 2021	0,1543	0,0730	0,1356	0,0656	0,0805	0,0979	0,1585	0,1286	0,1238
III 2021	0,1607	0,0744	0,1351	0,0684	0,0822	0,1049	0,1606	0,1398	0,1535
II 2021	0,1715	0,0753	0,1343	0,0675	0,0875	0,1054	0,1705	0,1580	0,1642
I 2021	0,1738	0,0753	0,1341	0,0681	0,0775	0,1043	0,1721	0,1608	0,1660

Source: Bielska (2023).

Table A10.*Minimal risk of two-component portfolios, part 2/2*

	PKN LPP	PKN MBK	PKN OPL	PKN PEO	PKN PGE	PKN PKO	PKN PZU	PKN SPL
III 2023	0,0929	0,0890	0,0694	0,0841	0,0924	0,0821	0,0882	0,0849
II 2023	0,0925	0,0887	0,0694	0,0848	0,0922	0,0836	0,0892	0,0851
I 2023	0,0930	0,0883	0,0700	0,0842	0,0927	0,0826	0,0892	0,0837
XII 2022	0,0930	0,0880	0,0697	0,0846	0,0929	0,0831	0,0889	0,0835
XI 2022	0,0862	0,0785	0,0605	0,0789	0,0857	0,0760	0,0775	0,0760
X 2022	0,0887	0,0841	0,0478	0,0824	0,0886	0,0767	0,0759	0,0739
IX 2022	0,0917	0,0887	0,0402	0,0834	0,0896	0,0793	0,0670	0,0741
VIII 2022	0,0741	0,0742	0,0417	0,0701	0,0652	0,0693	0,0622	0,0673
VII 2022	0,0679	0,0679	0,0423	0,0667	0,0647	0,0660	0,0582	0,0637
VI 2022	0,0669	0,0669	0,0416	0,0651	0,0656	0,0644	0,0560	0,0625
V 2022	0,0906	0,0918	0,0481	0,0889	0,0771	0,0867	0,0761	0,0863
IV 2022	0,0907	0,0919	0,0386	0,0883	0,0890	0,0835	0,0734	0,0841
III 2022	0,0887	0,0915	0,0395	0,0884	0,0880	0,0846	0,0773	0,0843
II 2022	0,0799	0,0916	0,0388	0,0859	0,0880	0,0761	0,0723	0,0827
I 2022	0,0807	0,0917	0,0313	0,0865	0,0877	0,0769	0,0759	0,0837
XII 2021	0,0778	0,0917	0,0307	0,0864	0,0877	0,0773	0,0822	0,0829
XI 2021	0,1090	0,1125	0,0428	0,1115	0,1153	0,1067	0,0952	0,1238
X 2021	0,1335	0,1426	0,0582	0,1203	0,1400	0,1099	0,1101	0,1384
IX 2021	0,1401	0,1490	0,0618	0,1134	0,1422	0,0978	0,1133	0,1426
VIII 2021	0,1402	0,1505	0,0592	0,1052	0,1450	0,0854	0,1134	0,1348
VII 2021	0,1400	0,1593	0,0594	0,1061	0,1483	0,0868	0,1173	0,1456
VI 2021	0,1464	0,1597	0,0617	0,1032	0,1472	0,0725	0,1181	0,1445
V 2021	0,1414	0,1459	0,0627	0,1039	0,1454	0,0863	0,1118	0,1397
IV 2021	0,1481	0,1461	0,0820	0,1125	0,1410	0,1088	0,1113	0,1409
III 2021	0,1566	0,1547	0,0847	0,1476	0,1481	0,1440	0,1094	0,1567
II 2021	0,1678	0,1628	0,0929	0,1521	0,1665	0,1465	0,1148	0,1612
I 2021	0,1688	0,1626	0,0930	0,1519	0,1695	0,1466	0,1136	0,1622

Source: Bielska (2023).

Table A11.*Expected rate of return of minimal risk portfolios, part 1/2*

	PKN ALR	PKN ACP	PKN CDR	PKC CPS	PKN DNP	PKN KTY	PKN JSW	PKN KGH	PKN KRU
III 2023	-0,0021	0,0023	-0,0046	-0,0288	0,0099	-0,0054	-0,0048	-0,0038	0,0043
II 2023	-0,0073	-0,0091	-0,0069	-0,0318	0,0074	-0,0087	-0,0117	-0,0045	-0,0016
I 2023	-0,0136	-0,0181	-0,0139	-0,0435	-0,0047	-0,0154	-0,0158	-0,0094	-0,0071
XII 2022	-0,0109	-0,0185	-0,0096	-0,0383	-0,0013	-0,0014	-0,0100	-0,0069	-0,0057
XI 2022	-0,0406	-0,0334	-0,0296	-0,0493	-0,0249	-0,0241	-0,0343	-0,0334	-0,0286
X 2022	-0,0324	-0,0242	-0,0373	-0,0583	-0,0220	-0,0249	-0,0316	-0,0345	-0,0281
IX 2022	-0,0164	-0,0153	-0,0301	-0,0474	-0,0036	-0,0151	-0,0124	-0,0270	-0,0082
VIII 2022	0,0020	-0,0052	-0,0141	-0,0283	0,0066	-0,0141	0,0027	-0,0122	0,0007
VII 2022	-0,0106	-0,0076	-0,0206	-0,0197	-0,0039	-0,0084	-0,0206	-0,0179	-0,0084
VI 2022	-0,0090	-0,0044	-0,0131	-0,0175	-0,0060	-0,0047	-0,0195	-0,0153	-0,0052
V 2022	0,0117	0,0077	-0,0011	-0,0064	0,0120	0,0030	0,0047	-0,0089	0,0111
IV 2022	0,0203	0,0141	0,0068	0,0011	0,0191	0,0068	0,0117	0,0005	0,0194
III 2022	0,0193	0,0094	-0,0010	0,0018	0,0139	0,0083	0,0160	-0,0027	0,0181
II 2022	0,0272	0,0151	-0,0021	0,0062	0,0147	0,0188	0,0191	-0,0244	0,0291
I 2022	0,0268	0,0193	0,0040	0,0126	0,0168	0,0184	0,0194	-0,0217	0,0338
XII 2021	0,0277	0,0229	-0,0040	0,0220	0,0202	0,0194	0,0202	0,0039	0,0343
XI 2021	0,0907	0,0373	0,0214	0,0375	0,0415	0,0375	0,0657	0,0338	0,0831
X 2021	0,0711	0,0162	0,0021	0,0259	0,0272	0,0276	0,0384	0,0264	0,0668
IX 2021	0,0646	0,0116	-0,0188	0,0227	0,0265	0,0283	0,0349	0,0197	0,0512
VIII 2021	0,0479	0,0181	-0,0117	0,0199	0,0280	0,0431	0,0284	0,0315	0,0538
VII 2021	0,0341	0,0115	-0,0164	0,0142	0,0245	0,0376	0,0196	0,0427	0,0524
VI 2021	0,0414	-0,0019	-0,0329	0,0162	0,0335	0,0491	0,0200	0,0482	0,0574
V 2021	0,0219	0,0029	-0,0221	0,0137	0,0263	0,0390	0,0069	0,0472	0,0505
IV 2021	0,0319	0,0128	0,0001	0,0205	0,0430	0,0452	0,0168	0,0615	0,0677
III 2021	0,0027	0,0088	0,0003	0,0138	0,0468	0,0303	-0,0006	0,0409	0,0134
II 2021	-0,0194	0,0080	0,0036	0,0163	0,0511	0,0222	-0,0277	0,0162	-0,0077
I 2021	-0,0258	0,0093	-0,0033	0,0140	0,0746	0,0273	-0,0340	0,0097	-0,0160

Source: Bielska (2023).

Table A12.*Expected rate of return of minimal risk portfolios, part 2/2*

	PKN LPP	PKN MBK	PKN OPL	PKN PEO	PKN PGE	PKN PKO	PKN PZU	PKN SPL
III 2023	-0,0028	-0,0044	-0,0090	-0,0077	-0,0035	-0,0101	0,0038	-0,0009
II 2023	-0,0052	-0,0087	-0,0094	-0,0122	-0,0047	-0,0147	-0,0029	-0,0072
I 2023	-0,0099	-0,0130	-0,0180	-0,0143	-0,0101	-0,0180	-0,0064	-0,0140
XII 2022	-0,0066	-0,0110	-0,0190	-0,0116	-0,0075	-0,0170	-0,0074	-0,0110
XI 2022	-0,0346	-0,0390	-0,0280	-0,0353	-0,0355	-0,0400	-0,0331	-0,0316
X 2022	-0,0317	-0,0350	-0,0355	-0,0333	-0,0322	-0,0408	-0,0342	-0,0320
IX 2022	-0,0137	-0,0171	-0,0239	-0,0202	-0,0154	-0,0287	-0,0246	-0,0208
VIII 2022	0,0031	0,0025	-0,0112	-0,0004	0,0076	-0,0053	-0,0066	0,0007
VII 2022	-0,0106	-0,0104	-0,0094	-0,0101	-0,0056	-0,0129	-0,0129	-0,0090
VI 2022	-0,0090	-0,0093	-0,0084	-0,0080	-0,0077	-0,0115	-0,0102	-0,0076
V 2022	0,0105	0,0099	0,0031	0,0124	0,0046	0,0054	0,0019	0,0127
IV 2022	0,0185	0,0162	0,0143	0,0224	0,0183	0,0162	0,0062	0,0219
III 2022	0,0163	0,0139	0,0156	0,0223	0,0165	0,0191	0,0111	0,0229
II 2022	0,0376	0,0186	0,0166	0,0348	0,0191	0,0383	0,0177	0,0370
I 2022	0,0363	0,0190	0,0206	0,0333	0,0196	0,0356	0,0127	0,0350
XII 2021	0,0370	0,0192	0,0234	0,0349	0,0213	0,0389	0,0234	0,0401
XI 2021	0,0843	0,1119	0,0283	0,0939	0,0691	0,0874	0,0581	0,0880
X 2021	0,0654	0,0631	0,0172	0,0668	0,0450	0,0686	0,0377	0,0657
IX 2021	0,0503	0,0440	0,0127	0,0866	0,0386	0,0932	0,0340	0,0642
VIII 2021	0,0510	0,0367	0,0084	0,0851	0,0282	0,0875	0,0280	0,0698
VII 2021	0,0526	0,0245	0,0091	0,0838	0,0244	0,0887	0,0201	0,0530
VI 2021	0,0361	0,0236	0,0049	0,0918	0,0354	0,1115	0,0181	0,0607
V 2021	0,0258	0,0089	0,0020	0,0644	0,0275	0,0922	0,0071	0,0358
IV 2021	0,0321	0,0091	0,0149	0,0263	0,0339	0,0436	0,0100	0,0254
III 2021	0,0093	-0,0040	0,0054	-0,0034	0,0170	0,0028	-0,0116	0,0007
II 2021	-0,0113	-0,0296	-0,0030	-0,0214	-0,0119	-0,0098	-0,0222	-0,0235
I 2021	-0,0122	-0,0400	-0,0039	-0,0286	-0,0197	-0,0122	-0,0166	-0,0281

Source: Bielska (2023).

Table A13.*Portfolio return realised based on recommended shares of companies in the portfolio, part 1/2*

	PKN ALR	PKN ACP	PKN CDR	PKC CPS	PKN DNP	PKN KTY	PKN JSW	PKN KGH	PKN KRU
III 2023	-0,1128	-0,0464	-0,1384	-0,0658	-0,0459	-0,0492	-0,1250	-0,1192	-0,1129
II 2023	0,0280	0,0363	0,0050	-0,0255	-0,0085	0,0138	0,0468	0,0191	0,0101
I 2023	0,0371	0,0472	0,0304	0,0316	0,0203	0,0418	-0,0016	0,0192	0,0348
XII 2022	-0,0313	-0,0095	-0,0241	-0,0523	-0,0110	-0,1598	-0,0215	-0,0162	-0,0105
XI 2022	0,1869	0,0651	0,1307	0,0879	0,1642	0,1840	0,1704	0,1743	0,1474
X 2022	0,0615	0,0033	0,1228	0,0841	0,0329	0,0219	0,0397	0,0527	0,0697
IX 2022	-0,1139	-0,0535	0,0168	-0,1648	-0,1142	-0,1237	-0,1219	-0,0717	-0,1541
VIII 2022	-0,1824	-0,0873	-0,1518	-0,0937	-0,1577	-0,0480	-0,1931	-0,2078	-0,1229
VII 2022	0,1095	0,0416	0,0701	0,0389	0,1170	-0,0392	0,1537	0,0692	0,1069
VI 2022	-0,0765	-0,0548	-0,0853	-0,0713	-0,0369	-0,0383	-0,0780	-0,1148	-0,0853
V 2022	-0,0226	-0,0127	-0,0471	-0,0631	0,0050	-0,0343	-0,0197	0,0053	-0,0152
IV 2022	-0,0339	-0,0375	-0,1718	-0,0952	-0,0916	0,0400	-0,0122	-0,1093	-0,0349
III 2022	0,0611	0,0749	0,0464	0,0337	0,1156	0,0581	0,0843	0,0491	0,0864
II 2022	-0,0217	-0,0908	-0,0329	-0,1081	-0,0406	-0,0472	0,0006	0,1497	-0,0536
I 2022	-0,0412	-0,0596	-0,0548	-0,0898	-0,1166	-0,0261	-0,0385	-0,0141	-0,0320
XII 2021	0,0101	-0,0139	0,0291	0,0015	0,0556	0,0446	0,0071	-0,0095	0,0023
XI 2021	-0,1470	-0,1194	-0,0766	-0,0432	-0,0646	-0,0769	-0,1631	-0,0945	-0,0639
X 2021	0,2296	0,1358	-0,0113	0,0090	0,0774	-0,0102	0,0907	-0,0016	0,0486
IX 2021	0,0455	0,0332	0,1121	-0,0281	0,0247	-0,0568	0,1115	-0,0834	0,0547
VIII 2021	0,0709	0,0445	-0,0367	0,0672	0,0523	-0,0606	0,0104	-0,0795	0,0197
VII 2021	-0,0006	0,0439	-0,0252	0,1295	0,0922	0,0777	-0,0517	-0,0034	0,0898
VI 2021	-0,0413	0,0509	0,0915	-0,0231	-0,0255	0,0248	-0,0605	-0,0683	-0,0377
V 2021	0,2102	0,0387	0,0835	0,0433	0,1530	0,0528	0,2176	0,1124	0,3367
IV 2021	0,1137	0,0375	-0,0109	-0,0022	-0,0671	0,0847	0,0503	0,0369	0,0112
III 2021	0,0577	0,0081	-0,0697	0,0308	0,0405	0,0730	0,0655	0,0254	0,0441
II 2021	0,0563	-0,0243	-0,1316	-0,0757	-0,0905	0,0798	0,0369	0,0107	0,0548
I 2021	-0,0447	-0,0018	0,0546	0,0147	-0,1062	-0,0301	-0,0805	-0,0257	0,0125

Source: Bielska (2023).

Table A14.*Portfolio return realised based on recommended shares of companies in the portfolio, part 2/2*

	PKN LPP	PKN MBK	PKN OPL	PKN PEO	PKN PGE	PKN PKO	PKN PZU	PKN SPL
III 2023	-0,1274	-0,1138	-0,0426	-0,1019	-0,1204	-0,1109	-0,0945	-0,0877
II 2023	0,0278	0,0262	-0,0137	0,0102	0,0160	0,0039	0,0176	0,0312
I 2023	0,0117	0,0234	0,0332	0,0256	0,0174	0,0273	0,0187	0,0490
XII 2022	-0,0286	-0,0348	0,0087	-0,0151	-0,0170	0,0058	0,0239	-0,0363
XI 2022	0,1690	0,1683	0,1045	0,1414	0,1683	0,1360	0,1714	0,1322
X 2022	0,0258	0,0840	0,1111	0,0977	0,0339	0,1029	0,1020	0,1645
IX 2022	-0,1161	-0,1075	-0,1297	-0,1011	-0,1162	-0,0934	-0,1546	-0,0928
VIII 2022	-0,1932	-0,1892	-0,0860	-0,1777	-0,2321	-0,1709	-0,1358	-0,1614
VII 2022	0,1106	0,1132	0,0430	0,0877	0,0790	0,0803	0,0702	0,0824
VI 2022	-0,0746	-0,0771	-0,0440	-0,0805	-0,0505	-0,0839	-0,0736	-0,0734
V 2022	-0,0110	-0,0183	-0,0534	-0,0241	0,0044	-0,0204	0,0217	-0,0270
IV 2022	-0,0321	-0,0203	-0,1005	-0,0457	-0,0066	-0,0961	-0,0669	-0,0598
III 2022	0,1000	0,0722	0,0322	0,0480	0,0747	0,0320	0,0627	0,0360
II 2022	-0,1844	-0,0056	-0,0191	-0,0553	0,0040	-0,1382	-0,0882	-0,0575
I 2022	-0,0592	-0,0464	-0,0714	0,0055	-0,0486	0,0427	-0,0054	-0,0264
XII 2021	0,1435	0,0162	-0,0012	0,0174	0,0102	0,0212	0,0043	-0,0036
XI 2021	-0,0942	-0,1536	0,0567	-0,1195	-0,1656	-0,0957	-0,1207	-0,0859
X 2021	0,0089	0,2028	-0,0226	0,3277	0,0731	0,2390	0,0879	0,1915
IX 2021	0,0808	0,0991	-0,0229	-0,1395	0,0287	-0,1282	-0,0652	-0,0038
VIII 2021	0,0057	0,0630	0,0739	0,2526	0,0565	0,2833	0,0664	0,3147
VII 2021	0,0238	-0,0430	0,1169	0,0797	-0,0635	0,0756	0,0156	0,0417
VI 2021	0,0611	-0,0197	-0,0014	0,0011	-0,0606	-0,0784	-0,0153	-0,0409
V 2021	0,1743	0,2490	0,0043	0,1747	0,1605	0,0421	0,1474	0,1887
IV 2021	0,1321	0,0738	0,0404	0,1434	0,2351	0,0777	-0,0301	0,0339
III 2021	0,0474	0,0235	0,0445	0,0405	0,0411	0,0714	0,1373	0,0489
II 2021	0,0357	0,0743	-0,0291	0,0526	0,0326	0,0485	-0,0203	0,1063
I 2021	-0,0654	0,0253	-0,0117	0,0252	-0,0405	-0,0023	-0,0772	-0,0367

Source: Bielska (2023).

FROM MANAGEMENT DURING ANALOGUE SPACE MISSIONS TO INNOVATIVE RESEARCH IN SPACE

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Purpose: The main objective of the article is to summarize the results of research conducted as part of the “Space Architecture” research project, which was established in 2017 under the supervision of Prof. Klaudiusz Fross at the Faculty of Architecture of the Silesian University of Technology. The article presents the most important results of research from analog space missions in LunAres habitats. At the same time, the article highlights the role of the 8-year Research Project, which led PhD student Wiktoria Dziadula to conduct a research experiment as part of the IGNIS space mission.

Design/methodology/approach: The following methods were used: expert qualitative assessment of the facility (based on a proprietary methodology based on simplified POE – Post Occupancy Evaluation, in terms of technical, functional, organisational, economic and behavioural quality), observations of the behaviour of mission participants, short surveys, conversations and interviews with the crew during the mission.

Findings: Conclusions and guidelines were obtained for the design of space facilities where people stay, including analogue space habitats on Earth, space stations and hotels, and residential bases on Mars or the Moon. Answers were obtained to the questions: how can architecture positively influence rapid adaptation to extreme conditions? What solutions and design decisions help build a supportive environment. What influences the improvement of the quality of life and work.

Research limitations/implications: Conclusions were drawn within the limited scope permitted by the location and types of missions. The basis for drawing conclusions for design purposes was the participation of architecture students and specialists (researchers, architects, managers, etc.) in four analogue space missions in the LunAres habitat. Due to the extensive and multifaceted research material, only selected conclusions are presented in this article.

Practical implications: Based on the research findings, specific design guidelines were formulated for space objects and other objects operating in extreme conditions.

Social implications: An important objective was to conduct observational studies of user behaviour and ways of using the habitat. Observations of relationships that occur in group cooperation during missions.

Originality/value: Research in the space habitat is conducted by the participants themselves. For the purposes of the research, original methods of qualitative assessment and observational research were developed.

Keywords: space architecture, qualitative research, analog space missions.

Category of the paper: Research paper.

1. Introduction to the subject

The main and important reason for this article is the recent achievements of PhD student Wiktoria Dziadula¹, who, together with the Extremo Technologies² team, conducted research during the Ax-4 mission on the International Space Station during the stay of Polish astronaut Dr Sławosz Uznański-Wiśniewski. This research is part of the Space Volcanic Algae project. It is an experiment that involves testing extremophile microalgae in microgravity conditions. The organisms under study, which are resistant to environmental conditions, have the ability to produce oxygen and valuable bioactive compounds, making them a potential component of future life support systems in space habitats. The aim of the research is to test the possibility of using these microorganisms in closed space ecosystems and in sustainable architectural systems on Earth³. Due to the confidential nature of the research, the article only describes how it was conducted, without providing any data from the results. As Wiktoria Dziadula states: Participation in the Space Volcanic Algae project was one of the most important experiences in my scientific and professional career to date. The opportunity to work on such a prestigious project and in such a legendary place as the Kennedy Space Centre, where we prepared the experiment before launch, was an extraordinary experience, both professionally and personally. It was a moment that confirmed my belief that courage in thinking, consistency and passion can take you really far. The entire work on the experiment has been going on for over 1.5 years", says Wiktoria Dziadula. It involved preparations, research and the construction of the experiment as part of the IGNIS mission – the first Polish technological and scientific mission organised by the Ministry of Development and Technology, the Polish Space Agency and the European Space Agency. Of course, the launch of the rocket on 25 June was a key moment for the experiment to be placed in orbit under the supervision of Dr Sławosz Uznański-Wiśniewski⁴. As already mentioned, due to the closed nature of the research and the fact that the analysis of its results has only just begun, the article does not provide any data.

¹ Currently, a student at the Doctoral School of the Silesian University of Technology, she is working on her doctoral thesis entitled: „Architecture in Extreme Conditions: The Problem of Self-Sufficiency in Space Architecture and Its Impact on Sustainable Development”, under the guidance of dr hab. inż. arch. Klaudiusz Fross, Prof. PŚ.

² A project involving doctoral student and architect Wiktoria Dziadula-Crisosto, oceanographer Ewa Borowska, and engineer Weronika Urbańska.

³ The ‘green’ box from the Space Volcanic Algae experiment with red microalgae, known from photographs, held by astronaut Dr Sławosz Uznański-Wiśniewski during his stay at the International Space Station.

⁴ According to the information posted on www.polsl.pl.

As analogue astronaut and architect Wiktoria Dziadula states: The Space Architecture Research Programme initiated by Professor Klaudiusz Fross at the Faculty of Architecture of the Silesian University of Technology was a great support on my scientific path. When choosing a field of study such as space architecture, I never thought that I would be able to develop in Poland. This subject was practically non-existent in Poland, only abroad, mainly in the USA. I seriously considered moving abroad for my master's degree, but this programme encouraged me to stay at the Silesian University of Technology, and I continued my academic career there, completing my master's degree and now my PhD in space architecture.



Figure 1. Visualisation of the space habitat concept, master's thesis by Wiktoria Dziadula, supervisor Prof. Klaudiusz Fross, Silesian University of Technology. Analogue astronauts Klaudiusz Fross, Igor Gdula and Wiktoria Dziadula. Wiktoria Dziadula at NASA and the Extremo Technologies team. Polish astronaut Dr Sławosz Uznański-Wiśniewski at the International Space Station during the Ax-4 mission and the green box of the Space Volcanic Algae experiment. (photo: archive Wiktoria Dziadula, Axiom/NASA/ESA, fb: International Space Station, Extremo Technologies, 2025)⁵.

⁵ more at: www.axiomspace.com, www.plinspace.pl.

Thanks to the support of Prof. Fross, who was one of the first to recognise the potential in this field, as part of the programme I had the opportunity to conduct my own research work in the Lunares analogue habitat, as well as in the Santander habitat in Spain, co-create the only Space Architecture Research Club in Poland, present projects at international conferences and develop my skills. All these steps led me to a research internship at the world's only space architecture centre in Houston, where, under the supervision of NASA experts, scientists and world-class specialists from the space sector, I conducted research for my PhD. I am currently fulfilling what is probably every scientist's dream – I am co-creating an experiment that is currently in orbit, which I had the opportunity to prepare in a NASA laboratory with the Extremo Technologies team. They say that a journey of a thousand miles begins with a single step, and for me, that first step was definitely the Space Architecture Research Programme and the support and open-mindedness of my supervisor, Prof. Klaudiusz Fross⁶ (Figure 1).

2. Methodology, purpose and scope of research

The main objective of the article is to highlight the significance and summarise the results of research conducted as part of the Space Architecture Research Project, which was established in 2017 under the supervision of Prof. Klaudiusz Fross at the Faculty of Architecture of the Silesian University of Technology. The article also presents the path taken by doctoral student and architect Wiktoria Dziadula, the main co-implementer of the Research Programme. It presents the research process from master's theses, through analogue space missions (simulated conditions on the Moon) to real research in space as part of the Ax-4 mission (Figure 2). Interesting research was conducted by architecture student Natalia Ściora during the PEGASUS analogue space mission. It focused on detailed analyses of space utilisation and space management. The research and conceptual designs for the space habitat⁷ were partially published⁸. This article, however, provides a comprehensive summary of the research conducted in space habitats and as part of the Scientific Programme of Space Architecture (SPSA) (Dziadula, Fross, 2022).

⁶ Quoted from Wiktoria Dziadula, July 2025.

⁷ More broadly in: Fross, Dziadula, 2022, Analog..., p. 57.

⁸ Four publications: Fross, 2023; Dziadula, Fross, 2022, About...; Fross, Dziadula, 2022, Analogowe...; Fross, Dziadula, 2022, Qualitative...; Fross, Dziadula, 2021.



Figure 2. The Extremo Technologies team at NASA, USA (photo: archive Wiktoria Dziadula).

2.1. Purpose and scope of research

The scope of the research presented in the article is limited to four analogue space missions in the LunAres habitat. The aim of the research was to assess the quality of the habitat, learn about the living conditions in the habitat and the procedures. The second aim was to observe the behaviour of users. It was important to obtain conclusions and guidelines for the design of space facilities where people stay, including analogue space habitats on Earth (Häuplik-Meusburger, Bishop, 2021; Häuplik-Meusburger, 2020; Heinicke, Orzechowski, Avila, 2020), space stations and hotels, and residential bases on Mars or the Moon (20). Of course, this was limited by the space and types of missions available. The basis for obtaining results and conclusions for design was the participation and conduct of planned research by architecture students and specialists (researchers, architects, designers, managers, etc.) in analogue space missions in the LunAres habitat. As part of the Space Architecture Research Programme, four analogue space missions and one foreign study trip took place between 2021 and 2024. These were, in order, the following international missions: ‘Panda’ (2021, LunAres) (Fross, Dziadula, 2022; Fross, Orzechowski, Dziadula, Mintus, 2022), ‘Sirius’ (2022, LunAres), ‘Pegasus’ (2024, LunAres), the innovative 24-hour mission “Weninger” (2023, LunAres) (Fross, 2023), and the foreign study visit ‘Santander’ (2023, Spain) (Figure 3).



Figure 3. Participants in analogue space missions in the LunAres habitat: ‘Panda’ (2021, LunAres), ‘Sirius’ (2022, LunAres), ‘Pegasus’ (2024, LunAres), the innovative 24-hour mission “Weninger” (2023, LunAres) (photo: archive Wiktoria Dziadula, Igor Gdula, Natalia Ściora, Klaudiusz Fross).

Architecture students participating in professional international missions performed all tasks specified in the mission programme under the supervision of commanders. At the same time, they conducted individual qualitative and observational research under the supervision of Prof. Klaudiusz Fross from the Silesian University of Technology. In each mission, it was important to prepare the research materials (scope of research, survey forms, interview questions, etc.) in advance and to manage the research during the stay in the habitat. It should be mentioned that conducting research in parallel with the mission tasks was not easy. The participants had a carefully planned schedule for the entire day, and their free time was limited. The participants (analogue astronauts) formed an international team of different ages and professions who did not know each other beforehand. Before each mission, a meeting was held between the leader, Prof. Klaudiusz Fross from the Silesian University of Technology, and the participant, during which the objectives and scope of the research were discussed. After each mission, another meeting was held to discuss the course of the mission, the results of the research and to receive a detailed written report. Each participant was required to submit a research report. The scope of the research concerned the qualitative assessment of the habitat itself as well as various aspects of behaviour and relationships between users (mission participants). The researchers were also free to modify the planned research and adapt it to the possibilities available during the mission.

2.2. Research methodology

During all four analogue space missions (PANDA, SIRIUS, WENINGER, PEGASUS), the following were used: expert qualitative assessment of the facility (based on a proprietary methodology based on simplified POE – Post Occupancy Evaluation, in terms of technical, functional, organisational, economic and behavioural quality), observations of the behaviour of mission participants, short surveys, conversations and interviews with the crew during the mission. Attempts were made to answer the following questions: how can architectural design positively influence rapid adaptation to extreme conditions? What design solutions and decisions help to build a supportive environment? What improves the quality of life and work? Also in terms of the psychology of space. At the same time, analogue astronauts participated in the research objectives of individual missions. In the PANDA mission: crew management and procedure training, and the study of behaviour in isolation. Research on the impact of isolation on human health, well-being and reactions (Fross, Dziadula, 2022).

Supplementary research: The impact of freeze-dried food on dental health. In the SIRIUS mission: Psychological study of the level of immersion of mission participants and the impact of replacing freeze-dried meals with everyday food products. Supplementary research: The human factor in space missions. In the PEGASUS mission: Crew management and procedure training involving a person in a wheelchair.

Interesting research was conducted by architecture student Natalia Ściora (during the PEGASUS mission) (Figure 5). It focused on detailed analyses of space usage and space management. The aim of the research was to assess how habitat users move around, compare the paths of each user, and compare the way they move during days with spacewalk simulations (EVA) and without spacewalk simulations. Before the mission began, tables were prepared for data collection by analogue astronauts.

The method involved a set of tables placed on the doors to each room – upon entering, it was necessary to note: which room you came from, the time of entry; the time of exit, which room you were going to, what you did in that room, and how much time you spent in the room. According to Natalia Ściora, each of the analogue astronauts received a set of tables to fill in themselves during designated days of the mission. Data was collected at the beginning of the mission (days 3 and 4), in the middle of the mission (days 7 and 8) and at the end of the mission (days 12 and 13). Each pair of days includes a day with a spacewalk simulation (days: 3, 7, 13) and days without these simulations (days: 4, 8, 12). Six members of the M2.24 mission crew took part in the study. Before the start of isolation, the crew was informed about the planned study and how it would be conducted. The study, entitled ‘User Paths,’ was designed to examine how people move around the habitat during the mission and the changes that occur over time (comparison of the beginning, middle and end of the mission).

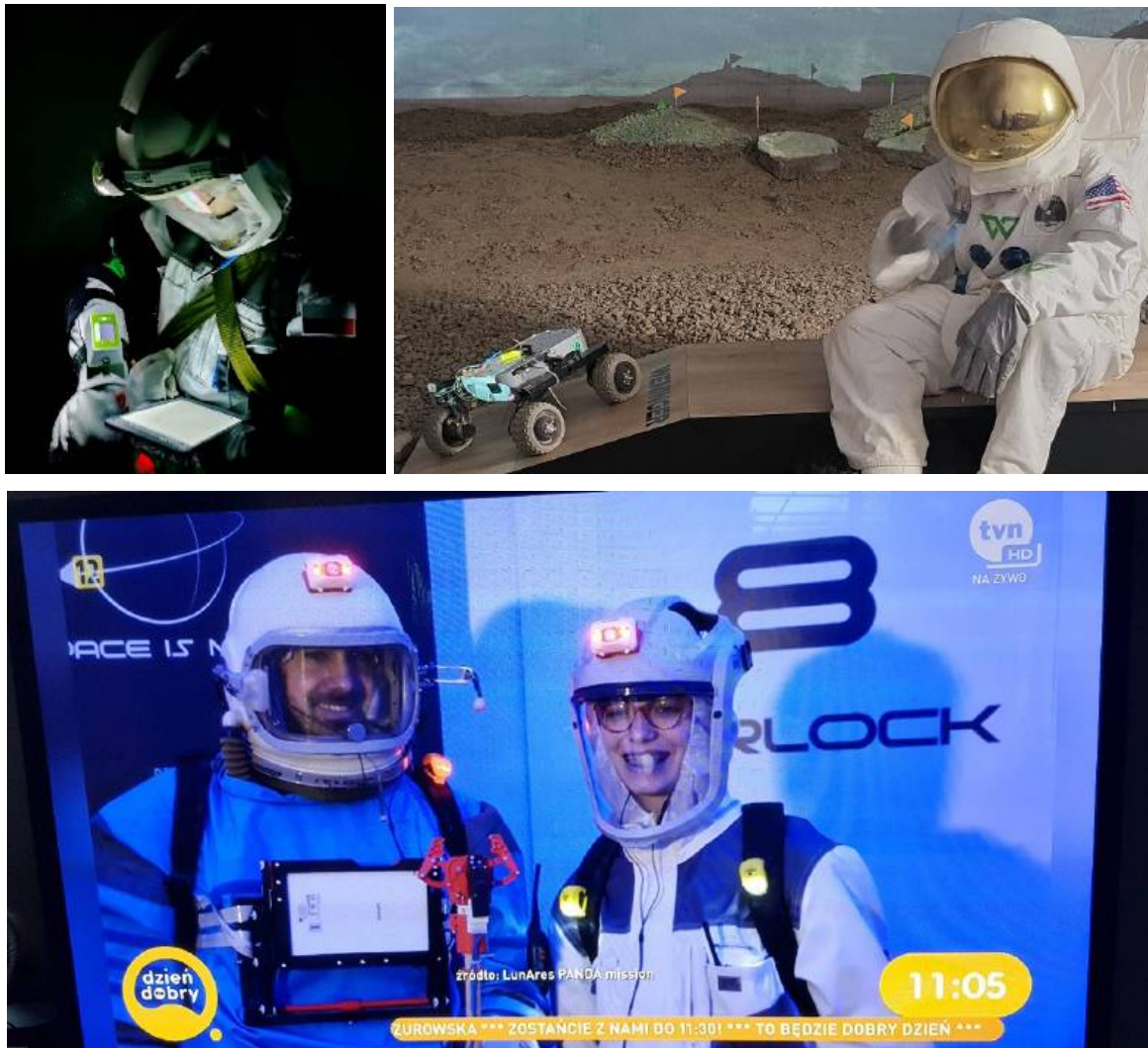


Figure 4. During the analogue PEGASUS, WENINGER and PANDA missions. The PANDA mission was featured on the Dzień Dobry TVN television programme (photo archive: Klaudiusz Fross).

The method involved a set of tables placed on the doors to each room – upon entering, it was necessary to note: which room you came from, the time of entry; the time of exit, which room you were going to, what you did in that room, and how much time you spent in the room. According to Natalia Ściora, each of the analogue astronauts received a set of tables to fill in themselves during designated days of the mission. Data was collected at the beginning of the mission (days 3 and 4), in the middle of the mission (days 7 and 8) and at the end of the mission (days 12 and 13). Each pair of days includes a day with a spacewalk simulation (days: 3, 7, 13) and days without these simulations (days: 4, 8, 12). Six members of the M2.24 mission crew took part in the study. Before the start of isolation, the crew was informed about the planned study and how it would be conducted. The study, entitled ‘User Paths,’ was designed to examine how people move around the habitat during the mission and the changes that occur over time (comparison of the beginning, middle and end of the mission)⁹.

⁹ According to the research report from the ‘User Paths’ mission, Natalia Ściora, 2024.



Figure 5. Round-the-clock monitoring of mission participants and microclimate parameters in the habitat, as well as all resources, including oxygen, drinking water, grey water, waste, etc. Architecture student Natalia Ściora during the PEGASUS mission (photo archive: Klaudiusz Fross, Natalia Ściora).

The author of the study adapted the data collection method on an ongoing basis to the conditions prevailing in the habitat, as each member of the crew had their own individual projects. For this reason, the data collection method was simplified as much as possible and adapted to the conditions and possibilities prevailing in the habitat. This simplification involved the removal of certain points originally included in the data collection.¹⁰ During the 14 days in the habitat, analogue astronaut Natalia Ściora also observed the behaviour of the participants. The people taking part in the mission were diverse in terms of age, nationality and education. The paths of each crew member in the habitat depended on their tasks, assigned roles and behaviour. For example, a person acting as a Biolab Officer and willing to help with other tasks will spend more time between the biolab and other rooms. On the other hand, a person focused only on their own tasks will mostly limit their paths to the rooms necessary for them. During data collection during the mission, there were two main problems with the proper completion of the sheets. The first problem was that the crew forgot to complete the table – despite reminders to fill in the tables, there were situations where crew members forgot to complete their paths on an ongoing basis¹¹.

¹⁰ According to the author of the study, despite the use of these measures, the data collected is incomplete and does not always represent the actual route taken by a given user during a given day. Modifications to the data collection method are needed to eliminate errors, possibly through automation of the process.

¹¹ According to the research report from the 'User Paths' mission, Natalia Ściora, 2024.

2.3. Research results

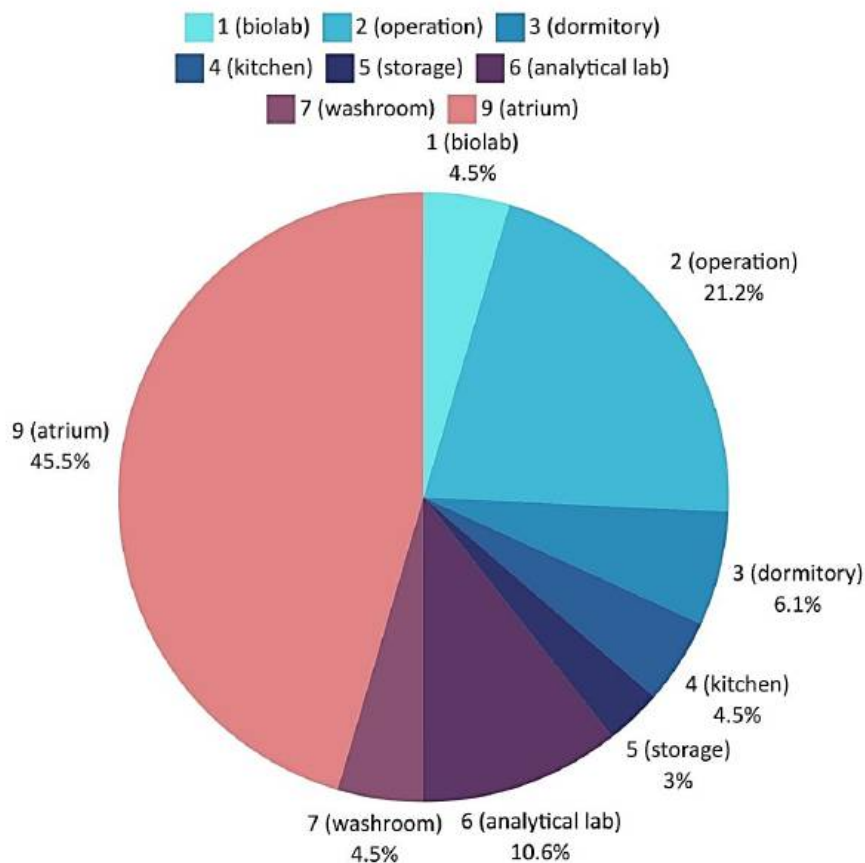
The results of research from individual space missions were compiled in the form of comprehensive reports. They provided many guidelines for designing structures in extreme conditions (habitats, bases and space stations). The conclusions drawn can be used not only for programming, designing and creating concepts for space habitats on Earth, bases in space, space settlements or hotels, but also for facilities on Earth where people stay in confined spaces for long periods of time (e.g. submarines, mining), such as bases in extreme conditions (e.g. in Antarctica).

participant no. 1*		participant no. 2*	
room no.	frequency	room no.	frequency
1 (biolab)	6	1 (biolab)	4
2 (operation)	7	2 (operation)	4
3 (dormitory)	9	3 (dormitory)	7
4 (kitchen)	5	4 (kitchen)	6
5 (storage)	2	5 (storage)	2
6 (analytical lab)	10	6 (analytical lab)	12
7 (washroom)	6	7 (washroom)	7
8 (airlock)	4	8 (airlock)	15
9 (atrium)	39	9 (atrium)	31
10 (EVA area)	0	10 (EVA area)	2

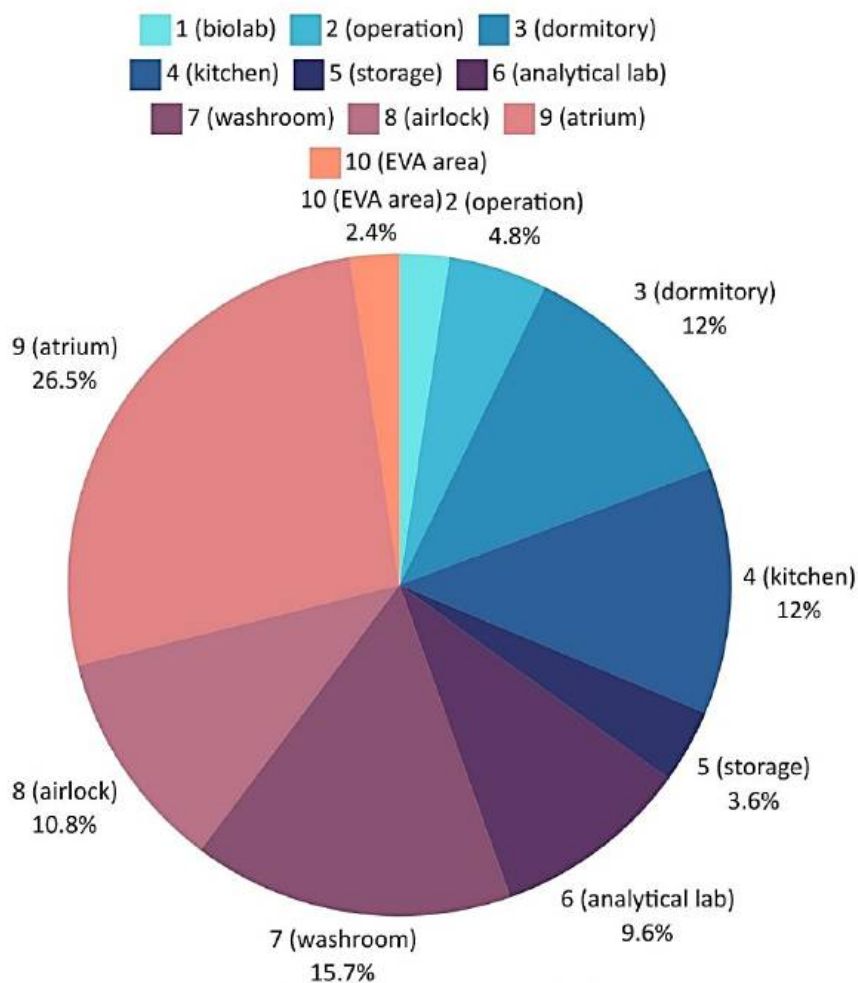
Figure 5. Research results (author: Natalia Ściora).

Selected conclusions may also provide a scientific basis or inspiration for innovative solutions for working in windowless rooms (e.g. large-area shops, factory and warehouse halls), micro-apartments, mini-houses, energy self-sufficient facilities, defence infrastructure (such as bunkers and shelters), as well as concepts for underground cities in the future (as alternatives and perhaps responses to the needs and limitations of the world of the future) (Figure 5)¹².

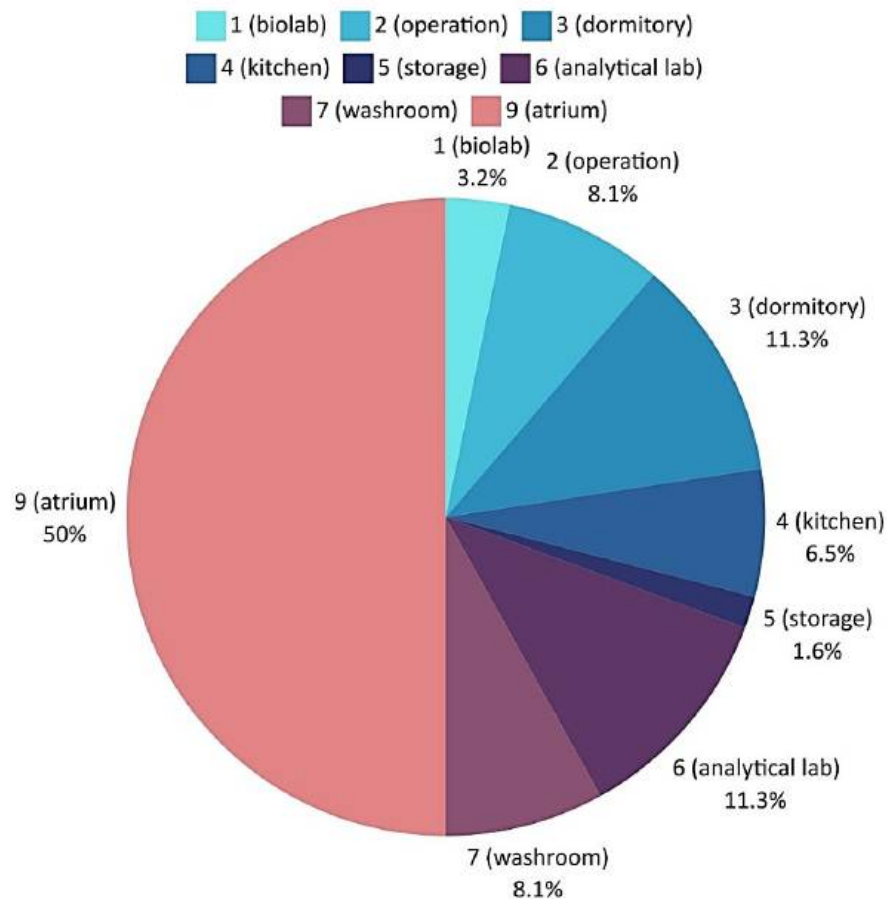
¹² According to Klaudiusz Fross, Summary of research based on reports from analogue space missions, Space Architecture Research Project – Scientific Report 2017-2025.



pie chart no. 5.3.1:
presentation of data from the table
mission day: 7/ participant no. 1



pie chart no. 5.3.2:
presentation of data from the table
mission day: 7/ participant no. 2



pie chart no. 5.3.3:
presentation of data from the table
mission day: 7/ participant no. 3

Results from day 7 of the mission:

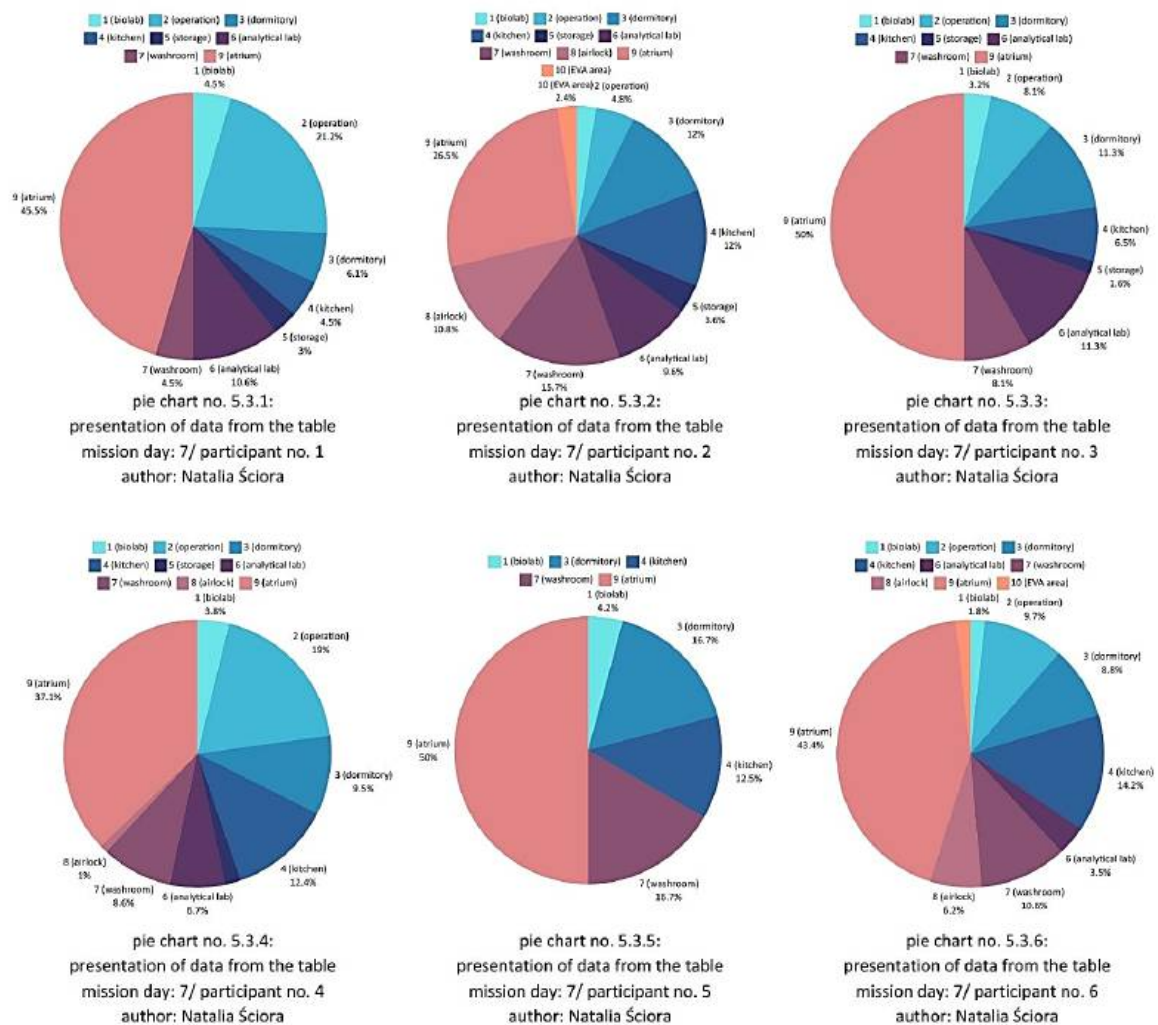


Figure 6. Users Paths – results of research from day 7 of the PEGASUS mission. Comparison of diagrams from 6 participants and 3 selected diagrams in enlarged view with the possibility of detailed data analysis (author: Natalia Ściora).

Below are some examples of observations and conclusions from the reports. The atrium also played an important role during the EVA simulation – it is the place from which the mission is managed, all preparations are organised and the simulation is concluded. The atrium is surrounded by other rooms, so it was often a ‘stop’ in the users' paths. On each of the days studied, all crew members spent most of their time in the atrium. This is due to the fact that the crew had organised workspaces in the atrium and most crew members preferred to work in the company of others (faster exchange of information, being among others during complete isolation also improved their mood). The rooms that were used the least were the airlock and the storage room. For some crew members, this also included the operations room and the biolab. The path of a person moving around in a wheelchair is in most cases different from that of the rest of the crew. Although all rooms (except for the EVA area – test subject no. 5 did not participate in EVA simulations as an EVA team member) were adapted for wheelchair access (ramps were added before the mission), her path is significantly shorter than that of the others.



Figure 7. Participants of the PEGASUS mission and Klaudiusz Fross during the WENINGER mission after leaving the EVA zone (photo archive: Klaudiusz Fross, Natalia Ściora).

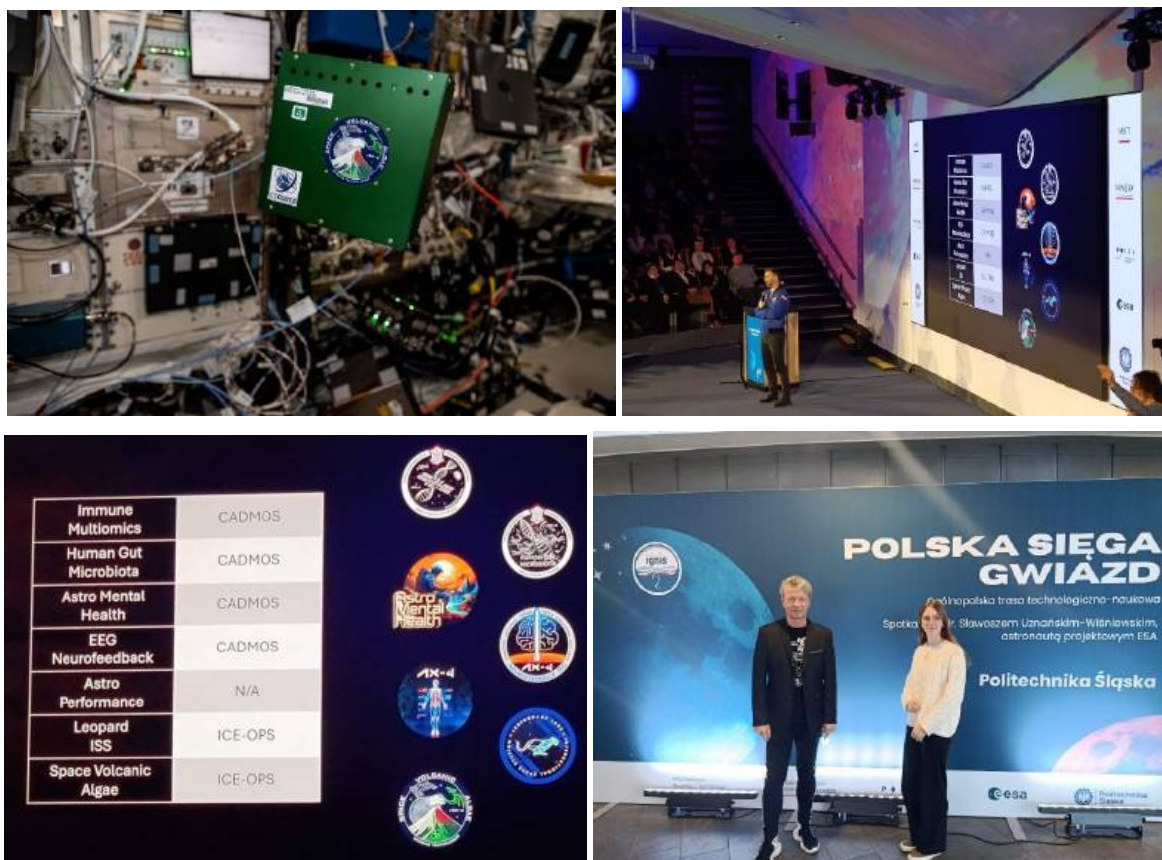


Figure 8. The ‘green’ box of the Space Volcanic Algae experiment with red microalgae. Polish astronaut Dr. Sławosz Uznański-Wiśniewski presenting research experiments conducted during the mission, including Space Volcanic Algae, during a meeting at the Silesian University of Technology. (photo: Axiom/NASA/ESA, fb: International Space Station, Extremo Technologies 2025; Klaudiusz Fross 2025)¹³.

The study entitled ‘User Paths’ provided a wealth of information on both the data collection method and the research results. The creation of successive versions of spreadsheets with tables allowed us to develop the best method for collecting data in mission conditions (each crew member has their own tasks to perform, related to the habitat infrastructure, the daily life of

¹³ more at: www.axiomspace.com, www.plinspace.pl.

a group of six people, and the performance of their own research/projects). The summary of the collected data in the form of tables and pie charts allowed us to present the rooms that were used most and least frequently. This showed how users use the habitat depending on their roles and degree of disability, and how these paths changed during the mission. In addition, differences between days with and without EVA simulation were revealed (Figure 6)¹⁴.

3. Summary and conclusions

Many people have asked why we should conduct research in space when we have so many problems on Earth. The results of space research are already having a significant impact on improving the quality of life on Earth. We are largely unaware of how many valuable space inventions we currently use on Earth, e.g. freeze-dried food used by mountaineers, travellers and in diets, smartphone cameras, scratch-resistant glass in spectacles, flexible polyurethane foam, infrared thermometers, smoke detectors, water filters, portable vacuum cleaners, headsets, frozen food and airtight packaging, baby food, computer mice, swimsuits, autonomous cars, air traffic control systems, grooved surfaces, foil blankets and memory foam (Fross, Dziadula, 2021).

Currently, the most well-known and commonly used building materials on Earth are concrete (reinforced concrete), steel, ceramics, glass, and wood. These materials are unlikely to find widespread use in space, mainly due to their weight and the associated costs of transporting them by rocket. In space, materials are needed that can be made from processed regolith, i.e. rock from the Moon or Mars. Regolith, as a weathered, fragmented, surface layer covering the planets, can be used to produce ‘Moon Concrete’ or ‘Mars Concrete’ on site, in space conditions. Other materials that can be considered include graphene composites or innovative hybrid nanomaterials with many functions specific to the conditions prevailing in space. Polymers, which when mixed with regolith through 3D printing can form structures for space objects, can be considered another material of the future. The space materials of the future will certainly be developed in laboratories on Earth with the participation of civil engineers, materials scientists, architects and researchers from many other fields. There is certainly a chance that some technologies, after space testing, could also be used on Earth in the future (Fross, Dziadula, 2021).

Our research focused mainly on assessing the quality of interiors and aspects of teamwork, human behaviour in isolation, and other interpersonal relationships. It provided many valuable tips, inspiration, ideas, and warnings about potential hazards. Extreme space conditions do not forgive mistakes, which can be catastrophic. The research conducted in the habitats yielded

¹⁴ According to the research report from the ‘User Paths’ mission, Natalia Ściora, 2024.

a number of interesting conclusions. Selected ones are listed below (Gabler 1986; Heinicke, Orzechowski, Avila, 2020).

The most important conclusions, according to the Space Architecture Research Project manager

Based on the research conducted, the manager of the Space Architecture Research Project formulated a number of conclusions. The eight most important ones are listed below:

1. The advantage of a crew (e.g. of 6 people) may be diversity in terms of age and generation, gender, education and profession. In critical situations, this gives a better chance of solving a problem (based on the WENINGER mission).
2. Contact with 'real' greenery (in the form of interior decoration or bionic crops) is one of the most important needs affecting well-being, emotional connection with Earth, family home, and the environment left behind for the duration of the mission (based on the SIRIUS mission).
3. Measurement of all parameters, resources, supplies, and waste (e.g., oxygen, water, grey water, food, rubbish, etc.) and individual consumption (e.g. how much water a person uses per shower or toilet flush) provides knowledge, increases awareness and responsibility for fellow crew members, the environment and the planet (based on the PANDA, SIRIUS and PEGASUS missions).
4. Even 24 hours in confinement without access to the outside world (windows) causes a loss of time, while 14 days causes a complete loss of sense of time. In such a case, in order to maintain a 24-hour circadian rhythm (day and night), artificial regulation of the day and night based on a clock is necessary. One way to do this is to use smart lighting that mimics daylight (e.g. Philips dynamic lighting) or another form of light signalling (conventional change in colour and intensity of artificial lighting) to indicate whether it is day or night. In the LunAres habitat, such regulation is possible (based on the PANDA, SIRIUS, PEGASUS and WENINGER missions).
5. Use of the latest technologies (wall-sized LED screens, TeamLab technology, etc.) to visually simulate the 'left behind' world, e.g. displaying images (static, animated, from live cameras) of nature (park, forest, landscape), life among people (in the city, in the countryside, contact with friends) (based on the PANDA, SIRIUS, PEGASUS, WENINGER missions).
6. Use of the latest technologies (MR - mixed reality, VR - virtual reality, etc.) to visually simulate the 'left behind' earthly world, e.g. displaying images (static, animated, from live cameras) of nature (park, forest, landscape), life among people (in the city, in the countryside, contact with friends) (based on the PANDA, SIRIUS, WENINGER missions).

7. The use of 3D printing technology as a basic necessity resulting from the lack of a component (e.g. during a Mars rover failure) or other item (e.g. everyday use). The inability to leave the habitat to go to a shop and the lack of an item in the unit's warehouse meant that 3D printing was the only and most important action in emergency situations (based on the PANDA mission).
8. While staying in the habitat, important for well-being and comfort, apart from rooms and 'work' areas (related to the mission objective), a common room for everyone (a place for meetings and conversations, a sense of connection, of being in a group), and the possibility of individual isolation (the need to be alone with one's thoughts) (based on the PANDA and PEGASUS missions)¹⁵.

"For me, as an architect, researcher, teacher and designer, Space Architecture frees me from my daily routine and gives me the incredible passion of a designer-traveller into the unknown. But a question I have been asked many times is: Don't we have enough problems to solve on Earth without worrying about space? Another question arises from the above: Why do we need space architecture? It is obvious that space architecture offers new possibilities, freedom of thought, a creative design context and specific design conditions, as well as new technological challenges. Research conducted in different conditions allows both architects and students to unleash their research imagination. Space solutions for self-sufficient residential buildings can have a significant impact on the development of future construction on Earth"¹⁶.

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¹⁵ According to Klaudiusz Fross, Summary of research based on reports from analogue space missions, Space Architecture Research Project – Scientific Report 2017-2025.

¹⁶ Quote: Klaudiusz Fross, author's statement.

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UNDERSTANDING THE CHALLENGES OF STARTING A BUSINESS FOR GENERATION Z

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Purpose: The study aims to identify, characterize, and classify the key barriers to undertaking entrepreneurial activity among representatives of Generation Z.

Design/methodology/approach: The research is based on a survey conducted in Poland among a sample of 262 university students, employing factor analysis to identify major meta-factors of obstacles. This methodological approach enables the extraction of the principal dimensions of barriers to entrepreneurship.

Findings: The results reveal four main categories of barriers: lack of experience and ideas, financial constraints, time management difficulties, and psychological concerns. The findings confirm the need for comprehensive support measures encompassing financial assistance, education, and confidence-building initiatives.

Research limitations/implications: The study is exploratory in nature and based on a non-representative sample of young people in Poland, which limits the generalizability of the results. This implies the need for further research involving larger and more diverse samples.

Practical implications: The results highlight the necessity of providing financial, educational, and psychological support to enhance young people's propensity toward entrepreneurship. The findings suggest the implementation of entrepreneurship education programs and initiatives aimed at reducing economic and mental barriers.

Social implications: Supporting youth entrepreneurship may contribute to increased innovation and competitiveness of the economy, thereby improving overall quality of life and social attitudes toward risk-taking.

Originality/value: This study offers a novel contribution by examining entrepreneurial barriers among Generation Z students, using recent quantitative data and advanced factor analysis, which had not been previously applied to this group.

Keywords: Generation Z, youth entrepreneurship, barriers to entrepreneurship development.

Category of the paper: research paper.

1. Introduction

The dynamic transformations occurring in the contemporary labor market present the young generation with entirely new challenges and opportunities in shaping their career paths (Lazar et al., 2023). Globalization, digitalization, and the development of new technologies have a profound impact on the structure of employment, the forms of work, and the expectations placed upon employers (Elayan, 2022). Increasingly, the traditional career model—based on stable employment within a single organization—is being replaced by more flexible forms of professional activity, including self-employment and entrepreneurship (Ma, Fang, 2024). In this context, entrepreneurship emerges not only as a means of fulfilling professional ambitions but also as an adaptive strategy for navigating the changing economic environment (Narojczyk, Nowak, 2025).

The current labor market is characterized by the coexistence of several generations that differ in their experiences, values, and approaches to work. Among them, Generation Z has attracted particular attention from researchers, as its members are now entering adult professional life. Born after 1995, these young individuals grew up in an era of ubiquitous access to digital technologies, social media, and instantaneous information flow (Vieira et al., 2024). They are characterized by a strong need for self-fulfillment, flexibility, and a pronounced desire to maintain a balance between professional and personal life. At the same time, they expect greater transparency, opportunities for development, and the ability to influence decision-making processes within organizations. Notably, new technologies have also created broader opportunities for young people entering the labor market to demonstrate entrepreneurial attitudes and behaviors (Lopes et al., 2024). In the face of these transformations, a growing number of Generation Z representatives are increasingly considering alternative career paths — including the establishment of their own businesses.

The aim of this article is to identify, characterize, and classify the key barriers to undertaking entrepreneurial activity among representatives of Generation Z. This approach allows for a better understanding of the factors that hinder young people from transitioning from stated entrepreneurial intentions to actual engagement, as well as the support mechanisms that could foster the development of their entrepreneurial potential. In the context of a rapidly changing labor market, increasing competition, and evolving expectations toward employers, this issue gains particular significance for both educational policy and business practice. To address the research objectives, a quantitative methodology was employed. The study is based on a structured survey conducted among 262 university students in Poland, all representing Generation Z. Data were analyzed using descriptive statistics and factor analysis to identify major dimensions of entrepreneurial barriers. The primary research hypotheses formulated in this study are: (1) Representatives of Generation Z identify distinct categories of barriers to undertaking entrepreneurial activity, and these barrier types are systematically associated with

their individual characteristics, motivations, and perceived risk levels; (2) These barriers can be classified into several specific meta-factors.

2. Literature review

A systematic review of current research was undertaken utilizing Google Scholar, ResearchGate, and ResearchRabbit to thoroughly examine the state of knowledge regarding entrepreneurial barriers among young adults. This synthesis revealed that while the issue is gaining considerable attention in contemporary scholarly discourse, most studies have focused on broader populations or older generational cohorts. Through critical evaluation of publication trends and findings, several 'holes' remain—especially in understanding the barriers distinct to Generation Z in Poland. According to the sources we were able to find, there are no studies referring and reporting on the comprehensive classification of entrepreneurial barriers specific to Generation Z within this national context. This substantiates both the relevance of our research and its contribution to filling a meaningful gap in current academic literature. In view of the above, the literature review cites findings from studies whose contextually relevant results correspond with the objectives adopted for this article.

In the study by Liguori et al. (2020) entrepreneurship is conceptualized as a conscious career choice associated with a high level of risk, uncertainty, and responsibility. The authors emphasize that the decision to establish a business constitutes a complex cognitive-motivational process, strongly dependent on individual attitudes, beliefs, and the socio-economic context. Utilizing the framework of the Social Cognitive Career Theory (SCCT), the researchers indicate that entrepreneurial intentions are shaped by both individual factors (such as self-efficacy and the need for autonomy) and environmental factors (e.g., institutional support, perceived risk, and expected benefits). The findings of these studies confirm that entrepreneurial intentions are among the most accurate predictors of actual entrepreneurial actions, surpassing the significance of variables such as personality or demographics. The authors also note that social and educational factors—including the entrepreneurial climate of higher education institutions—can either reinforce or weaken motivation to engage in entrepreneurial activity. For Generation Z, this implies that the decision to pursue entrepreneurship is not spontaneous but results from a prolonged process of intention formation, which requires appropriate conditions and support. Simultaneously, the complexity of this process means that young people often encounter cognitive and contextual barriers that hinder the transition from intention to action. From the perspective of research on entrepreneurial barriers among Generation Z, the SCCT framework helps to understand how environmental and personal factors interact to shape decisions regarding entrepreneurial career paths.

In the process of identifying and classifying barriers, attention should also be given to the research by Anjani and Darto (2023), which demonstrated that financial literacy, income, and self-control have a significant and positive influence on the financial behaviors of Generation Z. The strongest relationship was observed for self-control, suggesting that the ability to self-regulate plays a key role in responsible financial management. Financial knowledge promotes rational financial decision-making, while higher financial resources are associated with a more active approach to finances, although not necessarily with greater savings. These findings indicate that appropriate attitudes and competencies are more important than financial resources alone.

In contrast, Kılıç (2022) highlighted the relationship between entrepreneurial tendencies and life satisfaction among Generation Z, providing deeper insight into the motivations and barriers accompanying young people's engagement in entrepreneurial activity. The results show that an increase in entrepreneurial propensity is associated with higher levels of life satisfaction, suggesting that entrepreneurship constitutes an important aspect of self-fulfillment for this generation. At the same time, income levels were found to significantly differentiate attitudes toward entrepreneurship—individuals with lower incomes exhibited a higher need for achievement and a greater willingness to take risks. This may indicate that financial barriers do not necessarily discourage but rather motivate some members of Generation Z to seek alternative professional development paths through entrepreneurship. Consequently, the results suggest that the perception of barriers and opportunities among young people is closely linked to their aspirations, lifestyle, and individual sense of agency.

Entrepreneurial activity among Generation Z has recently attracted growing attention in both Polish and international research on youth entrepreneurship (Azoulay et al., 2020; Dzomonda, Neneh, 2023; Milovanska-Farrington, Mateer, 2024). The literature highlights various barriers that hinder this group from starting their own businesses. The most frequently identified obstacles include financial barriers, gaps in entrepreneurial education, psychological concerns, and institutional constraints.

First, financial barriers constitute one of the primary obstacles to the development of entrepreneurship among Generation Z. Authors emphasize that the lack of start-up capital and limited access to funding sources significantly constrain young people's willingness to undertake economic risks (Prakash, Arora, 2025; Wasilczuk, Karyy, 2022). In the Polish context, studies also indicate a deficit in practical financial management knowledge, which further complicates the transition from idea to venture implementation (Hasan et al., 2024; Wasilczuk, Karyy, 2022).

Second, psychological aspects, such as fear of failure, low self-confidence, and lack of experience, frequently inhibit entrepreneurial activity among young people. Research shows that despite high motivation and creativity (Wach, Bilan, 2023), there is a need for psychological support and mentoring to reduce these fears and increase readiness for entrepreneurial action (Prakash, Arora, 2025).

Third, educational barriers are significant. Engaging in entrepreneurship requires appropriate competencies, including knowledge of entrepreneurship and digital skills. Studies on Generation Z emphasize the need to strengthen educational programs that address the specific needs of this group, particularly in financial and digital literacy (Hasan et al., 2024; Wasilczuk, Karyy, 2022).

Furthermore, research on institutional barriers highlights issues related to bureaucracy, limited support from public institutions, and policies that are not adapted to the realities of young entrepreneurs (Wach, Bilan, 2021; Wasilczuk, Karyy, 2022). Cultural and social challenges are also noted, influencing Generation Z's approach to entrepreneurship, including attitudes toward risk and employment stability (Dvorský et al., 2019).

From this literature review, two main conclusions emerge. First, Generation Z faces multiple complex barriers to establishing their own businesses, requiring an interdisciplinary approach that combines financial, educational, and psychological support, as well as institutional reforms tailored to the needs of young entrepreneurs. Strengthening these areas is crucial to increasing entrepreneurship levels and leveraging this generation's potential in the labor market. Second, the reviewed studies highlight the need to fill a research gap by providing a comprehensive understanding of the barriers to entrepreneurial activity faced by Generation Z.

3. Methods

The empirical study on the barriers to undertaking entrepreneurial activity among Generation Z was conducted in June 2024 with a sample of 262 students from the Poznań University of Economics. The research was carried out using a structured questionnaire. Based on the conducted literature review as well as the authors' own observations and experiences, 14 factors were identified as elements hindering the initiation and management of business activities. The selection of respondents was based on a non-random, purposive sampling method targeting typical cases. The primary criterion for inclusion was belonging to Generation Z, defined as individuals born after 1995 and before 2012.

Table 1.
Characteristic of the survey sample

No.	Characteristic	No. of indications N = 262	Share (in %)
Gender			
1.	Female	155	59,16
2.	Male	105	40,08
3.	I will not give an answer	2	0,76
Study degree			
1.	I Degree	119	45,42
2.	II Degree	143	54,58

Source: own study based on empirical data.

The processing of empirical data was carefully controlled. The collected empirical material was verified, reduced, and subsequently transformed into an alphanumeric format using specialized software. For this purpose, the Statsoft Statistica 12 statistical package was employed, supplemented by Microsoft Excel spreadsheets. The processed data were then analyzed using descriptive statistics and factor analysis methods.

In an era of a rapidly changing labor market and technological progress, understanding the career aspirations of the younger generation becomes crucial for shaping future economic strategies. Generation Z, now entering the labor market, brings with it new values, expectations, and approaches to professional careers. One particularly significant aspect attracting research interest is their attitude toward starting their own businesses.

To better understand these aspirations, the study posed the question: "How do you envision your professional future?" This question aimed not only to map the general career intentions of this group but also to assess their readiness and willingness to establish their own enterprises. The distribution of responses is presented in Figure 1.

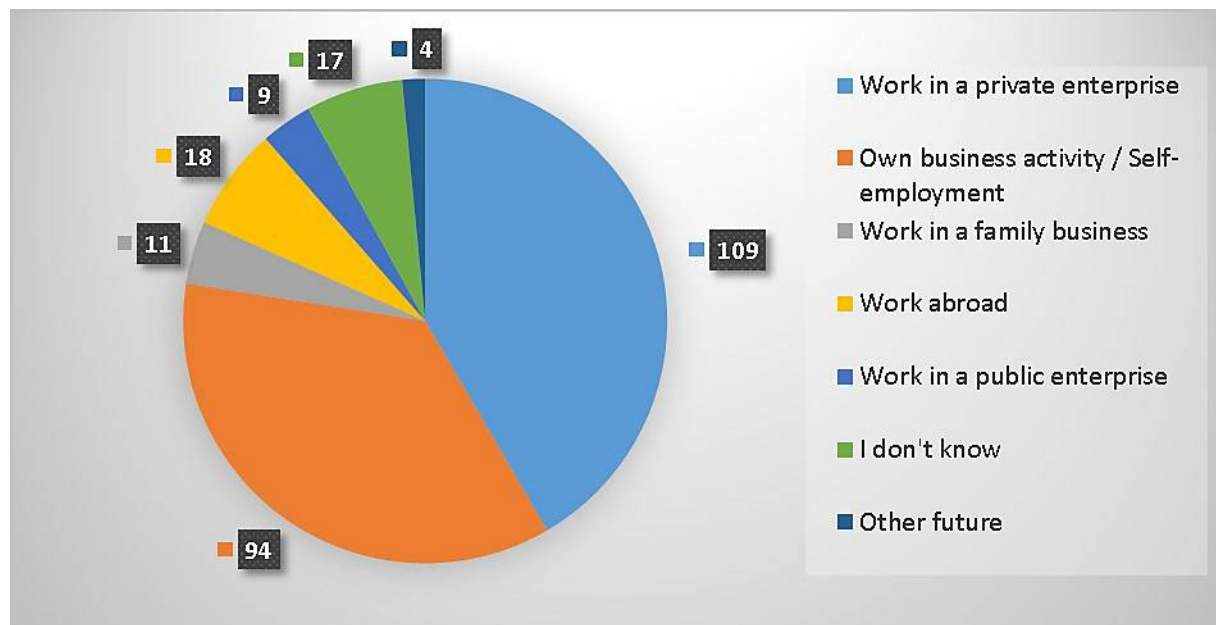


Figure 1. How do you envision your professional future?

Source: own study based on empirical data.

The conducted study on career aspirations among Generation Z reveals a diverse approach of young people toward professional paths. The largest group of respondents, 109 individuals (41.60%), envision their professional future within a private enterprise. This dominant response indicates a significant interest in stable employment within the private sector.

The second most common choice was starting their own business, indicated by 94 respondents (35.88%). This group demonstrates strong aspirations to independently shape their careers and manage their own companies, highlighting the high entrepreneurial potential within Generation Z.

Another group consists of individuals who see their future working abroad, selected by 18 respondents (6.87%). Additionally, 17 individuals (6.49%) had not yet defined their career plans, choosing the option "I don't know".

Working in a family business was indicated by 11 respondents (4.20%), suggesting the continuation of family professional traditions. Employment in a public enterprise was preferred by 9 individuals (3.44%).

A small group of respondents (1.53%) selected the category "other future," providing various individual career visions in free-text responses. Examples included: "Working abroad, own business", "I don't want to work", "I would like to work in a private company, but I would also like to try something of my own", and "Own business + part-time job to take vacations". These responses demonstrate that some young people seek unconventional solutions and combine different career models, reflecting their flexibility and creativity in planning their professional futures.

In summary, although the majority of respondents envision working within private enterprises, starting their own business represents a significant element of career aspirations among Generation Z. Strong entrepreneurial tendencies among young people may therefore play a crucial role in shaping the future economic landscape.

The next question posed in the study was: "Do you already run your own business?" The distribution of responses is presented in Table 2.

Table 2.

Do you already run your own business?

Response	Number of response	Percentage (in %)
No	250	95,42
Yes	12	4,58

Source: own study based on empirical data.

The vast majority, 250 individuals (95.42%), responded negatively, indicating that they do not currently run their own business. Only 12 respondents (4.58%) declared that they already manage their own company. These results are unsurprising given the young age of the respondents and the fact that many are still pursuing their studies, often at the university level. At this stage of life, it is natural that most young people focus on acquiring knowledge, professional experience, and personal development, which may translate into a lower propensity to take the risks associated with running a business. At the same time, particular attention should be given to the 12 respondents (4.58%) who already operate their own enterprises. It is commendable that despite their young age and ongoing education, they have decided to take on the challenge of managing their own business. Their courage, determination, and entrepreneurial spirit are worthy of recognition and may serve as an inspiration for other young individuals considering a similar career path.

The next question posed in the study was: "Do you plan to run your own business in the future?" Analyzing responses to this question allows for an assessment of the future entrepreneurial aspirations among Generation Z. The total number of responses in this category amounted to 250, which aligns with the previous question where 12 individuals were already operating their own businesses. The distribution of responses is as follows:

Table 3.

Do you plan to run your own business in the future?

Responde	Number of response	Responde
Definitely not	3	1,15
Rather not / Probably not	41	15,65
I don't know / Unsure	47	17,94
Rather yes / Probably yes	103	39,31
Definitely yes	56	21,37

Source: own study based on empirical data.

These results indicate that a significant portion of respondents express a positive attitude toward running their own business. As many as 103 individuals (39.31%) answered "rather yes", while another 56 respondents (21.37%) chose "definitely yes". In total, 159 respondents (60.68%) declare a willingness to operate their own business in the future. This high level of interest in entrepreneurship among young people suggests that Generation Z is ready to take risks and has strong aspirations to independently shape their professional careers. It may also indicate that young people seek greater autonomy and control over their professional lives, which is characteristic of their approach to work and career development.

4. Results

Generation Z has grown up in an era of rapid technological development and changing socio-economic conditions. This group of young people is often perceived as more flexible, innovative, and willing to take risks compared to previous generations. However, despite these positive attributes, there are numerous barriers that may hinder their ability to successfully start and manage their own businesses. Understanding and identifying the obstacles faced by Generation Z on the path to entrepreneurship can be crucial for the development of effective support programs, including those provided by the state.

Based on a review of the literature as well as the authors' own experiences and observations, a range of barriers affecting plans to undertake entrepreneurial activity has been identified. Analyzing their cognitive significance, these barriers were subsequently classified into the following groups (Table 4):

- Financial factors – encompassing all aspects related to business financing, such as capital availability, operational costs, and financial stability.
- Legal and regulatory factors – relating to the legal and regulatory requirements that entrepreneurs must face.
- Psychological factors – associated with personal fears, motivation, and self-confidence.
- Operational factors – concerning the daily challenges of managing a company and practical aspects of running a business.

Table 4.

Barriers to undertaking entrepreneurial activity according to identified groups

Category	Factors
Financial factors	- Lack of financial resources. - High costs of running a business. - Tax burdens (ZUS, tax office). - Lack of external funding. - Lack of regular income.
Legal and regulatory factors	- Applicable legal regulations. - Financial and legal responsibility. - Need for constant monitoring of the market situation.
Psychological factors	- Lack of self-confidence. - Fear of bankruptcy. - Risk of business failure.
Operational factors	- Lack of sufficient knowledge about running a company. - Lack of a good idea. - Irregular working hours.

Source: own study based on empirical data.

Within the conducted study, respondents were asked to evaluate these factors using a five-point Likert scale. Participants could indicate that a given factor had no significance by assigning 1 point, 2 – of little significance, 3 – of moderate significance, 4 – of high significance, and 5 – of very high significance. To determine the relative importance of the barriers, the arithmetic mean was calculated, defined as the significance coefficient. Subsequently, all variables were ranked from the highest to the lowest coefficient. Detailed data, including the mean score for the entire population, mode, frequency of the mode, and standard deviation, were organized in descending order of the significance coefficient and are presented in Table 5.

Table 5.

The significance of barriers to undertaking entrepreneurial activity

Factor	Descriptive statistics			
	Mean	Mode	Modal Frequency	Standard deviation
Lack of financial resources	4,15	5,00	117	0,96
High costs of running a business	3,93	4,00	118	0,89
Lack of a good idea	3,84	4,00	92	1,07
Risk of business failure	3,71	4,00	108	0,99
Tax burdens (ZUS, tax office)	3,67	4,00	98	1,03
Lack of sufficient knowledge about running a company	3,66	4,00	125	1,01

Cont. table 5.

Applicable legal regulations	3,53	4,00	112	0,98
Financial and legal responsibility	3,52	3,00	85	1,06
Lack of regular income	3,47	4,00	85	1,08
Lack of self-confidence	3,42	4,00	74	1,18
Fear of bankruptcy	3,38	4,00	83	1,16
Lack of external funding	3,35	3,00	104	0,95
Need for constant monitoring of the market situation	3,17	3,00	81	1,08
Irregular working hours	2,43	2,00	84	1,17

Source: own study based on empirical data.

Based on the importance indicator results presented above, an analysis was conducted of the three highest and three lowest rated barriers.

The lack of financial resources was assessed as the most significant barrier to undertaking entrepreneurial activity by Generation Z. The mean score of 4.15 indicates that young people consider access to capital as a key challenge that may substantially hinder starting one's own business. High initial costs, lack of financial support, and difficulties in obtaining credit are the main aspects of this barrier.

The second highest rated barrier is the high costs of running a business, with a mean score of 3.93. Generation Z recognizes that maintaining a company involves many fixed costs, such as renting premises, utility fees, employee salaries, and other expenses, which may pose a considerable financial burden.

The lack of a good business idea was rated at 3.84. Young people often grapple with the difficulty of finding a unique and profitable concept that could attract customers and stand out in the market. Creativity and innovation are key elements of success, and their absence constitutes a serious obstacle to starting a business.

Conversely, the lowest rated barrier was irregular working hours, with a mean score of 2.43. It appears that Generation Z does not perceive work time flexibility as a significant barrier. This may stem from their greater adaptation to remote work and flexible hours, which are becoming increasingly popular in the modern business environment.

The necessity of constant monitoring of the market situation, with a mean score of 3.17, is also assessed as less important relative to other factors. Young entrepreneurs are probably more open to dynamic market changes and adaptation, which may explain the relatively lower rating of this barrier.

The lack of external funding, with a score of 3.35, is also perceived as one of the less significant barriers by Generation Z. Although it remains an important issue, young people may be more inclined to seek alternative sources of financing, such as crowdfunding, angel investors, or startup support programs.

The results confirm Hypothesis 1, demonstrating the systematic association of barrier categories with individual characteristics and motivations.

However, the conducted analysis does not allow for an exhaustive interpretation and assessment of variables of priority significance. Some of the listed barriers have a similar cognitive load and exhibit high to moderate interdependence, which results in a rather chaotic and unclear overall picture. This issue should be addressed by reducing the number of primary variables and assigning them appropriate ranks. Therefore, in the next stage of the study, factor analysis was conducted, enabling the simplification of the complex structure to a format that allows for explanation of the issues on the basis of a limited number of significant mega-factors.

It was first necessary to determine the number of mega-factors describing the phenomenon under study. For this purpose, Cattell's scree plot was used (1966, pp. 245-276), which is the basis for identifying the point at which to choose the number of significant mega-factors. The essence of this criterion is the search for a gentle decline in eigenvalues. According to Cattell's concept, to the right of this point appears the so-called "factor scree", containing factors that marginally explain the analyzed phenomenon. On the presented plot (Figure 2), it is clearly visible that there is a gentle decline in eigenvalues between the fourth and fifth points. Therefore, in accordance with the adopted criterion, four mega-factors should be classified for further analysis.

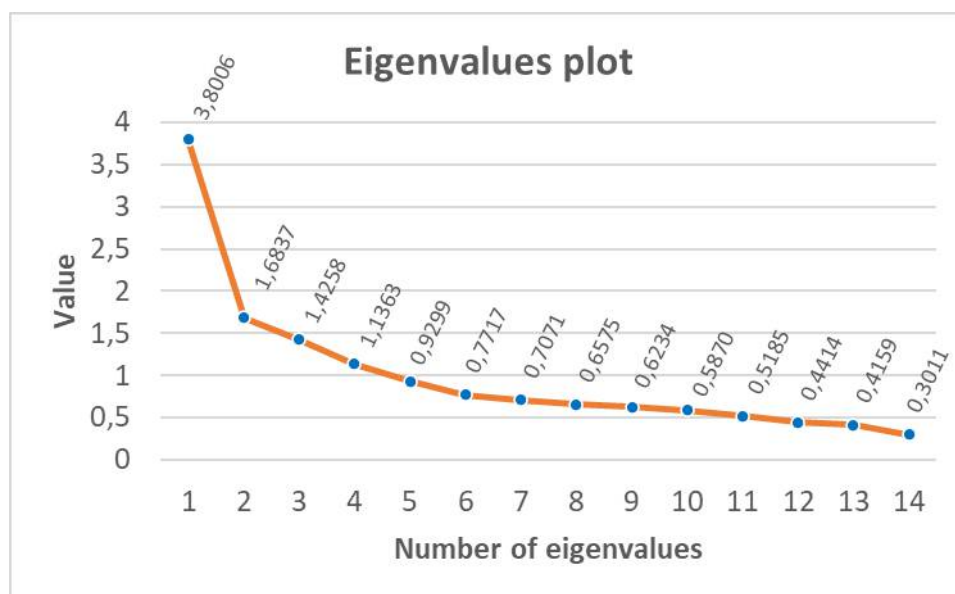


Figure 2. Cattell's scree plot for the assessment of barriers related to undertaking own business activity.

Source: own study based on empirical data.

To confirm the correctness of the selected number of mega-factors, the eigenvalues of the four identified main variables were verified, as presented in Table 6. In summary, it should be emphasized that the cumulative eigenvalue of all mega-factors amounted to 8.05, with the first factor obtaining an eigenvalue of 3.8.

Table 6.

Eigenvalues corresponding to successive mega-factors for the assessment of barriers related to undertaking own business activity

Mega-factors	Eigenvalue	Cumulative eigenvalue
F1	3,80	3,80
F2	1,68	5,48
F3	1,43	6,91
F4	1,14	8,05

Source: own study based on empirical data.

Subsequently, the rotation of raw factor loadings was performed using the Varimax method, which enables the maximization of the variance of these variable loadings (also referred to as factor purification) (Stanisz, Tadeusiewicz, 2007, p. 233). In practice, it is assumed that loadings exceeding a value of 0.7 have a significant impact on cognitive value, and this threshold was also adopted in the present analysis. Significant factor loadings, which represent the correlation between the extracted factor and the primary variables, are presented in Table 7.

Table 7.

Factor loadings matrix after raw Varimax rotation for the assessment of barriers related to undertaking own business activity

Variable	Factor loads			
	Factor 1	Factor 2	Factor 3	Factor 4
Lack of sufficient knowledge about running a company	0,77	0,11	0,07	0,09
Lack of a good idea	0,72	-0,13	0,12	0,19
High costs of running a business	0,03	0,74	0,06	0,19
Lack of self-confidence	0,33	-0,09	0,17	0,71
Fear of bankruptcy	0,01	0,20	0,05	0,88
Tax burdens (ZUS, tax office)	-0,13	0,75	0,16	0,08
Irregular working hours	-0,04	0,06	0,76	0,07
Need for constant monitoring of the market situation	0,13	0,05	0,77	0,13
Lack of regular income	0,17	0,14	0,71	0,09

Legend: Factor analysis with raw Varimax rotation was applied; in the construction of mega-factors, loadings with a value greater than or equal to 0.70 were used. The presented data include only those factors classified as main factors.

Source: own study based on empirical data.

The extracted mega-factors explained nearly 60% of the variance of the research problem. Each mega-factor was named in a way that reflects the unique characteristics of Generation Z.

The first mega-factor (Inexperienced Innovators), which explained 27.10% of the variance, was constructed from the following factors: lack of sufficient knowledge about running a company and lack of a good idea. Generation Z, often characterized by innovation and a desire to introduce new ideas, may encounter barriers resulting from a lack of experience and knowledge in managing their own business. Although many young people have ambitious ideas, a lack of adequate educational and mentoring support makes them feel unprepared to take the risks associated with entrepreneurship. This group of young people needs access to knowledge and tools that will help them transform their innovative ideas into successful businesses.

The second mega-factor (Financial Startup Barriers), which explained 12.00% of the variance, was composed of the following factors: high costs of running a business and tax burdens (ZUS, tax office). One of the greatest challenges facing Generation Z is the financial barriers related to starting a business. High initial costs, such as administrative fees, equipment purchases, and premises rental, can effectively discourage young entrepreneurs. Additionally, tax burdens and bureaucracy constitute further obstacles, impeding a smooth business start. As a result, many young people abandon their dreams of their own business in favor of more stable, albeit less satisfying, career paths.

The third mega-factor, named "Time Jugglers", which explained 10.20% of the variance, consisted of the following factors: irregular working hours, the need for constant monitoring of the market situation, and lack of regular income. Generation Z, which values flexibility and work-life balance, often experiences pressure linked to irregular working hours and the necessity of continuous market monitoring. The lack of income stability can cause stress and uncertainty, which in turn negatively affects their motivation to start their own business. Young people fear that starting their own business will require sacrificing a significant portion of personal life and free time, which contradicts their desire for harmony between work and personal life.

The fourth mega-factor, defined as "Uncertainty of Tomorrow", explained 8.10% of the variance and consisted of the following factors: lack of self-confidence and fear of bankruptcy. Uncertainty and apprehensions related to entrepreneurship are strong barriers for Generation Z. Lack of belief in one's own capabilities and fear of bankruptcy effectively inhibit their willingness to take the risks associated with starting a business. A heightened sense of financial uncertainty, especially in the face of a dynamically changing market, means that young people often choose safer professional options. They require psychological support and practical tools that will help them overcome their fears and build self-confidence.

Detailed data concerning the construction of factors, their eigenvalue, and degree of variance explanation are presented in Table 8.

Table 8.
Summary of mega-factors

Megafactor	Factor loads	Percentage of variance explanation	Cumulative percentage of variance explanation
Inexperienced Innovators	- Lack of sufficient knowledge about running a company - Lack of a good idea.	27,10	27,10
Financial Startup Barriers	- High costs of running a business. - Tax burdens (ZUS, tax office).	12,00	39,20
Time Jugglers	- Irregular working hours. - Need for constant monitoring of the market situation. - Lack of regular income.	10,20	49,40
Uncertainty of Tomorrow	- Lack of self-confidence. - Fear of bankruptcy.	8,10	57,50

Source: own study based on empirical data.

The above descriptions of the mega-factors and the variable table provide a more comprehensive picture of the phenomenon under study. Each of these mega-factors offers valuable insights into the challenges and obstacles that young people from Generation Z encounter on their path to entrepreneurship. The factor analysis validates Hypothesis 2 by classifying the barriers into specific meta-factors, reflecting financial, psychological, time-management, and experience-related constraints.

5. Discussion

Based on the results of the conducted research, several important conclusions can be drawn regarding the future of Generation Z and their potential impact on the labor market and entrepreneurship. Each of these meta-factors points to specific challenges that require appropriate strategies and support.

- The need for education and mentoring – The meta-factor "Inexperienced Innovators" highlights the necessity of providing young people with appropriate entrepreneurship education and mentoring. To overcome these barriers, governments, universities, non-profit organizations, and educational platforms should implement a wide range of online courses covering entrepreneurship, business management, marketing, finance, and law. Governments and universities possess the resources and authority to develop educational programs tailored to market needs, while non-profit organizations and educational platforms can introduce innovative and flexible teaching methods. Furthermore, the establishment of business incubators and accelerators by NGOs, financial institutions, and corporations can offer mentoring, financial support, and access to business networks. Local chambers of commerce, entrepreneurs, and educational institutions can also organize regular workshops and webinars focusing on the practical aspects of starting and managing a business.
- Financial and regulatory support – The meta-factor "Financial Start-up Barriers" emphasizes the need for financial support programs and simplification of tax and bureaucratic regulations. To overcome these barriers, governments, NGOs, and financial institutions should establish grant programs and microfinancing options to help young entrepreneurs cover the initial costs of running a business. Governments and local authorities have legislative power to introduce tax reliefs that reduce financial burdens on new enterprises. Promotion of crowdfunding platforms and angel investor networks by NGOs can also assist young entrepreneurs in obtaining funds and mentorship support.

- Promotion of work-life balance and flexible work arrangements – The meta-factor "Time Jugglers" suggests that Generation Z values flexibility and balance between professional and personal life. Technology companies, start-ups, and educational institutions should promote and provide access to tools for time management and work organization, such as Trello, Asana, or Slack. Outsourcing companies, employment agencies, and NGOs can encourage young entrepreneurs to use outsourcing services to focus on the core aspects of their businesses. Employers, non-profits, and public health institutions should promote flexible working hours and remote work opportunities, while also providing psychological support and stress management workshops.
- Psychological support and confidence-building – The meta-factor "Uncertainty of Tomorrow" indicates the need for psychological support and programs that enhance self-confidence. Young entrepreneurs often fear risks associated with failure and bankruptcy, making training and coaching sessions essential for coping with anxiety and stress. NGOs, chambers of commerce, and universities should create coaching and mentoring programs where experienced entrepreneurs share their knowledge and support young people in building confidence. Consulting firms, educational institutions, and non-profits can organize risk management training, showing young entrepreneurs how to identify and mitigate business risks. Media, NGOs, and government agencies can promote entrepreneurship through public campaigns highlighting the successes of young entrepreneurs and inspiring others to take similar initiatives.

With appropriate support and implementation of these measures, Generation Z can contribute to the creation of innovative start-ups, promote flexible and sustainable work models, increase the number of social enterprises, and accelerate the digital transformation of the economy. Educational, financial, and psychological support will be crucial to their success and their ability to transform the labor market.

Based on the research findings, several directions for future studies on barriers to entrepreneurship among Generation Z can be formulated:

- Psychological aspects of entrepreneurship – One important avenue for future research is to examine the impact of psychological support on young people's self-confidence and entrepreneurial success. As a new generation, Generation Z faces challenges related to self-efficacy and fear of failure. Coaching programs, stress management workshops, and other forms of psychological support may be key in building confidence among young entrepreneurs. Future studies could analyze how different types of psychological support influence decision-making, coping with failure, and overall motivation to engage in entrepreneurship.
- Long-term effects of flexible work models – Another important area of research involves analyzing the long-term effects of implementing flexible working hours and remote work opportunities on work-life balance, productivity, and innovation among young entrepreneurs. Generation Z values flexibility and the possibility to work from

anywhere, which may significantly influence their approach to entrepreneurship. Research findings could help determine how flexible work models affect mental health, professional engagement, and the capacity for innovation in entrepreneurial activities, as well as how such models can support or hinder entrepreneurship development in the long term.

- Gender differences in entrepreneurship – A further research direction is to explore differences in entrepreneurial approaches between women and men in Generation Z, as well as to identify specific barriers and support needs for both groups. Studies could focus on the challenges faced by young women and men in starting and managing their own businesses, the strategies they employ to overcome these challenges, and the types of support that are most effective. Understanding these differences may help develop more personalized support programs that address the unique needs of both groups, thereby fostering entrepreneurship across the entire Generation Z cohort.

Throughout the discussion, our results are deliberately and directly compared with those found in the international literature, ensuring a strong link between the review, methodological section, and empirical analysis. By explicitly referencing recent studies and drawing distinctions with our findings, we provide clarity and rigor for readers and reviewers alike.

A key limitation of the present study is that its policy recommendations remain general and are not explicitly aligned with current EU or national regulatory frameworks supporting youth entrepreneurship. At the EU level, strategic initiatives such as the Youth Entrepreneurship Policy Academy (YEPA), the European Commission's EntreComp framework, and targeted funding instruments—including Erasmus for Young Entrepreneurs and the Youth Start-Up Competition (YSC 2025)—create a robust landscape of support instruments and benchmarks. These frameworks promote the development of entrepreneurial skills across education levels, improve access to finance, and systematically support incubation and mentoring programs for young people.

In the Polish context, national programs such as “Pierwszy Biznes – Wsparcie na Startcie” (First Business – Start-up Support) and the “Młodzi Przedsiębiorcy” (Young Entrepreneurs) initiative provide practical, measurable instruments: low-interest loans, mini-grants, training, and partnerships among universities, business incubators, and government agencies. Additionally, university-level entrepreneurship education—exemplified by curricular modules, business incubators, and national competitions—is regulated and promoted through the Ministry of Family, Labour and Social Policy's Youth Guarantee Initiative and the activities of PARP (Polish Agency for Enterprise Development).

Future research should systematically examine the tangible impact of these EU and national policy instruments on the reduction of entrepreneurship barriers among Generation Z in Poland. In particular, comparative evaluations of the effectiveness of university-based entrepreneurship curricula, mentorship networks, and financial support programs—measured against both regulatory objectives and benchmarking frameworks such as EntreComp—will be crucial in

developing more targeted and effective recommendations. This approach will directly connect the studied constructs and measurement variables with both educational and policy environments.

Further research in these areas could not only deepen understanding of the barriers facing Generation Z but also contribute to the development of more effective strategies and support programs that enable young people to succeed in the labor market and in entrepreneurship.

6. Summary

The article focuses on identifying and analyzing the key barriers to undertaking entrepreneurial activity among Generation Z in Poland. A survey conducted with a sample of 262 students revealed four main meta-factors hindering youth entrepreneurship: lack of experience and insufficient business ideas, financial barriers, difficulties in time management, and psychological concerns related to risk and uncertainty. The results confirm that despite high entrepreneurial aspirations among young people, their propensity to start businesses is primarily constrained by lack of capital, the cost of running a business, fear of failure, and deficits in practical knowledge. Effective support is considered to include financial programs, comprehensive entrepreneurship education, as well as psychological support and mentoring. Given the survey-based nature of the study, further exploration of this issue across different subpopulations of Generation Z is recommended. From a social perspective, fostering youth entrepreneurship can contribute to increased innovation and improved quality of life by enhancing the economic and social activity of this group.

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BETWEEN TRANSPARENCY AND PERSUASION: COMPARATIVE ANALYSIS OF ESG VISUALIZATION STRATEGIES IN POLISH RETAIL LEADERS' REPORTS

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Purpose: This study investigates ESG data visualization strategies employed by Polish retail leaders, examining how visualization choices reveal underlying communication approaches and whether mandatory disclosure frameworks achieve transparency objectives.

Design/methodology/approach: Multiple case study analysis of 2023-2024 sustainability reports from three Polish retail chains (Lidl Polska, Biedronka, Żabka) employing systematic visual inventory (287-469 elements per report), semiotic analysis of exemplar visualizations, and functional coding across six communicative purposes. The integrated analytical framework combines visual rhetoric theory, corporate legitimacy theory, and greenwashing literature.

Findings: All three retailers demonstrate near-complete avoidance of conventional charts (averaging 0.19% of visual elements) despite extensive numerical disclosure, revealing “compliant obscurity” - technical CSRD adherence through formats systematically minimizing stakeholder evaluation capacity. Analysis identifies visual greenwashing as comprehensive strategic architecture operating through five mechanisms: analytical visualization avoidance, emotional substitution via intensive photography, aesthetic legitimization through design sophistication, semiotic naturalization normalizing corporate-favorable assumptions, and symbolic efficiency replacing substantive disclosure. While organizational characteristics shape specific manifestation, core architecture converges across cases. Semiotic analysis reveals how materiality matrices present corporate interest prioritization as objective measurement, photographs naturalize inequalities as partnerships, and infographics reframe threats as opportunities.

Research limitations/implications: Three-case sectoral focus limits generalization; single-year analysis cannot reveal longitudinal evolution. Future research should extend analysis cross-sectorally, track visualization evolution, and investigate actual stakeholder report usage patterns.

Practical implications: Companies should embrace analytical visualization as credibility foundation and balance emotional elements with transparency. Investors and civil society should recognize chart avoidance as red flag, develop semiotic analytical capabilities, and demand visualization transparency through format-oriented reporting standards.

Social implications: Findings reveal fundamental gap between CSRD regulatory objectives and documented practices, suggesting content-focused regulation enables sophisticated greenwashing when format requirements are absent, informing regulatory development and enhancing civil society capacity for critical ESG report evaluation.

Originality/value: First systematic comparative analysis of ESG visualization strategies in Central-Eastern European retail under CSRD implementation. Advances literature by identifying visual greenwashing as sector-specific systematic architecture integrating multiple elements, demonstrating how mandatory frameworks enable compliance without ensuring transparency.

Keywords: ESG reporting, data visualization, greenwashing, visual rhetoric, CSRD, Lidl, Biedronka, Żabka.

Category of the paper: Research paper.

1. Introduction

Environmental, Social, and Governance (ESG) reporting has transitioned from voluntary corporate social responsibility practice to regulatory requirement across the European Union. The Corporate Sustainability Reporting Directive (CSRD), effective from 2024, mandates that approximately 50.000 European companies - including major Polish retailers - adopt standardized disclosure frameworks (European Parliament and Council, 2022). This regulatory shift raises critical questions about how companies communicate sustainability performance beyond mere compliance with reporting frameworks.

Visual communication represents a particularly consequential yet under-studied dimension of ESG reporting. While academic attention has focused extensively on textual disclosure content, narrative strategies, and framework adoption (Hahn, Kühnen, 2013; Dumay et al., 2016), the visual elements occupying substantial report real estate - charts, infographics, photographs, diagrams - have received limited systematic analysis. This gap is especially pronounced in Central and Eastern European contexts, where emerging ESG reporting practices intersect with distinct market conditions, consumer expectations, and organizational cultures.

Visual elements serve strategic communication functions beyond simple information transfer. Research demonstrates that companies use graphs selectively to emphasize positive performance (Beattie, Jones, 2008), employ photographs to manage legitimacy impressions (Hrasky, 2012), and leverage visual complexity to obscure poor performance (Cho et al., 2012). Yet comprehensive understanding of how visualization choices reveal underlying communication strategies remains limited, particularly in comparative organizational contexts.

This study addresses these gaps through systematic analysis of ESG visualization strategies employed by three leaders in Polish retail: Lidl Polska, Biedronka, and Żabka. These companies represent distinct business models (international discounter, Portuguese-owned market leader, Polish convenience chain), ownership structures (German corporate, Portuguese public, private equity), and ESG maturity levels, creating natural variation that enables pattern identification across organizational contexts.

1.1. Contribution to scholarly conversations

This research contributes to three ongoing academic debates. First, it engages with the transparency versus legitimization debate (Hahn, Lülfs, 2014; Cho et al., 2015): Do companies use ESG reports primarily to inform stakeholders transparently, or to manage impressions and maintain legitimacy? Visual analysis offers new empirical evidence, as visualization choices reveal underlying communication priorities - whether companies emphasize data precision (transparency orientation) or emotional connection (legitimation orientation).

Second, the study addresses the standardization versus contextualization tension (Dumay et al., 2016; Bebbington, Unerman, 2018): As ESG reporting becomes mandatory, how do companies balance regulatory compliance with distinctive brand communication? Visualization strategies may reveal how organizations navigate this tension, particularly when global frameworks meet local market contexts.

Third, this research contributes to the visual turn in accounting and corporate communication research (Davison, 2015): moving beyond exclusive focus on textual disclosure to understand how visual rhetoric shapes stakeholder perceptions of corporate performance. This study extends visual communication theory into the sustainability reporting domain through systematic, multi-dimensional analysis.

1.2. Research context: Polish retail sector

The Polish retail sector presents a particularly compelling context for several reasons. Regulatory pressure intensifies as Polish retailers face increasing ESG scrutiny from EU directives, stock exchange requirements (for listed parent companies), and evolving consumer expectations. The direct public visibility creates high reputational sensitivity, making ESG communication strategies consequential for brand perception and competitive positioning. Sector-specific challenges include supply chain complexity, packaging waste, labor practices, food waste, and energy consumption - topics requiring clear communication to diverse stakeholders.

Market maturity combines international players bringing established ESG practices with domestic companies developing localized approaches, creating rich comparative opportunities. Rising consumer awareness shows that Polish consumer consciousness regarding sustainability has grown significantly, with surveys indicating increasing willingness to consider environmental factors in purchasing decisions (PwC, 2024).

1.3. Research objectives and questions

The main research question guiding this exploratory study is: How do Polish retail leaders differ in their ESG data visualization strategies, and what do these differences reveal about their underlying communication approaches and organizational contexts?

This broad question is operationalized through four specific research questions:

- RQ1 (Structural Patterns): How do reports differ in volume, organization, and proportion of visual content, and what do these architectural choices reveal about communication priorities?
- RQ2 (Visualization Typologies): What types of visual elements dominate in each report, and how do companies balance data-driven versus emotion-driven visualizations?
- RQ3 (Communication Strategies): Do visualization patterns align with informational, narrative, or emotional strategies, and how do strategies relate to organizational characteristics?
- RQ4 (Brand Identity Integration): How does ESG visual strategy align with overall brand communication, and do companies leverage brand elements consistently?

Together, these questions enable systematic comparison of visualization practices while uncovering the strategic logics shaping how Polish retailers construct visual narratives of sustainability performance.

2. ESG reporting and data visualization in retail: literature review

2.1. ESG reporting in retail

In ESG reporting in retail is gaining strategic importance, but the industry faces challenges arising from its complex operational structure and strong dependence on global supply chains. Key difficulties include discrepancies and lack of standardization in reporting, limited transparency, low data comparability, and the need to integrate ESG indicators into daily operations (Bataeva, 2024; Paranhos et al., 2024). The challenge remains not only to standardize indicators, but also to ensure their consistency across supply chains that often include thousands of entities (Kalyanam, 2025).

The introduction of the CSRD (Corporate Sustainability Reporting Directive) directive in 2024 significantly changes ESG reporting rules in the European Union, including in Polish retail. New regulations impose an obligation for detailed reporting on environmental, social, and corporate governance issues on all large enterprises and listed SMEs. Reports must comply with the European Sustainability Reporting Standards (ESRS), covering over one hundred ESG indicators, and data is subject to independent audit (Čarnogurský, 2025; Matuszak-Flejszman et al., 2024). The aim of the regulation is to increase the comparability and credibility of non-financial information across the EU (Rega, 2025; Raimo et al., 2025). In Poland, the number of companies subject to reporting obligations will increase from about 300 to 3000-4000, covering not only large retail chains, but also their suppliers and business partners (Kos, 2025).

Regulatory pressure extends to the entire supply chain, as large companies require compliance with ESG principles from their contractors (Čarnogurský, 2025; Allgeier, Feldmann, 2023). For many smaller entities, this is an impulse to implement standards despite the lack of formal obligation. However, CSRD implementation can also bring benefits—improved access to financing, increased investment attractiveness, and strengthened reputation—although it is associated with the risk of greenwashing and high implementation costs (Pawlak, 2024; Matuszak-Flejszman et al., 2024).

Transparent and credible ESG (Environmental, Social, Governance) reporting has become a key tool for building and protecting corporate reputation. Research indicates that the retail and logistics sector is particularly advanced in using ESG reporting to build reputation, which results from close contact with consumers and pressure for transparency (Yu, 2025; Tamasiga et al., 2024). Companies that openly and consistently communicate their ESG activities are perceived as more ethical and trustworthy, which strengthens stakeholder loyalty (Yu, 2025; Odriozola, Baraibar- Diez, 2017; Meng et al., 2023), builds better relationships with the community and investors (Khamisu, 2024). In the retail industry, where supply chains are subject to particular public scrutiny, ESG communication supports dialogue with stakeholders and builds competitive advantage (Kalyanam, 2025; Tamasiga et al., 2024).

The impact of ESG reporting on reputation is based on several mechanisms. First, stakeholder perception—report transparency reduces information asymmetry and signals authentic commitment to sustainable development (Meng et al., 2023). Second, investor and public attention strengthens the reputation effect when ESG data is easily accessible and comparable (Bazrafshan, 2023). Third, quality and credibility of reports—standardized, verified, and data-based disclosures build trust more effectively than narrative-based declarations (Odriozola, Baraibar- Diez, 2017). Finally, technological innovations, especially artificial intelligence-based tools, streamline data collection and increase recipient trust (Ács et al., 2025).

2.2. Visualization in corporate communication

Contemporary corporate communication increasingly uses visualization as a strategic tool, crucial for building organizational identity and reputation. Images, charts, colors, and graphic layout become not only aesthetic elements, but also means of conveying values, credibility, and emotions (Degreef, 2024). As Yadav (2025) indicates, the development of non-financial reporting leads to combining quantitative data with narrative and visual symbolism, which allows companies to more effectively present their commitment to sustainable development.

The theory of visual rhetoric examines how images, colors, typography, and graphic layout convey meanings and emotions, shaping how the company is perceived by stakeholders (Greenwood et al., 2019; Davison, 2013). Visual elements serve not only an aesthetic, but also persuasive and narrative function—they explain, reinforce, or contrast with the content of

messages. Visual design based on rhetorical principles allows creating coherent messages that build credibility and support brand strategy (Veltsos, 2009; Davison, 2013).

A central concept in this context is corporate visual identity (CVI), encompassing name, logo, color scheme, typography, slogan, and other graphic elements. CVI ensures recognizability, expresses organizational values, and supports its reputation. Research indicates that individual CVI elements serve different functions: logo and name strengthen recognition, colors build mood and distinguish the brand, typography emphasizes professionalism, and slogan communicates values (Bosch et al., 2006; Lyu, 2023). Contemporary analyses of visual rhetoric combine semiotic approaches with content analysis methods, which enables examining visual aspects of reports and corporate documents (Greenwood et al., 2019). As a result, visual rhetoric becomes not only an aesthetic addition, but a key element of communication strategy, strengthening the identity and credibility of contemporary companies.

Visualization plays a growing role in corporate communication, allowing simplification of complex data and supporting decision-making. According to Cognitive Load Theory (CLT), effective visualizations should minimize excessive mental load on recipients, which increases understanding and message effectiveness. Research indicates that properly designed dashboards, graphs, and business models reduce cognitive load, facilitating information interpretation (Henike et al., 2020; Ke et al., 2023). However, excessive detail, unclear layout, or too much complexity can have the opposite effect—increase load and hinder perception (Kopacz et al., 2022; Huang et al., 2009).

The most commonly indicated principles of effective visualization include: clarity and simplicity (Cook, 2006; Eesee et al., 2025), adaptation to recipient competence (Ke et al., 2023; Hesson, 2021), and the modality effect, i.e., combining image with sound, which can reduce cognitive load in less experienced users (Banu et al., 2024; Bancilhon et al., 2023). The principle of simplicity involves eliminating unnecessary elements, using clear labels and appropriate contrast (Schwabish, 2021). Visualization readability should enable quick and intuitive understanding of information while avoiding excessive graphic elements that may distract the recipient's attention (Few, 2012). Well-designed visualization should guide the recipient's eye from the most important elements to less significant ones. Appropriate use of contrast, font sizes, colors, and arrangement allows building logical visual order (Knafllic, 2015). Meanwhile, unified color schemes and consistent use of colors support brand recognition and help distinguish data categories (Knafllic, 2015). It is important that the choice of visualization type results from the communication goal and recipients' knowledge level (Ancker et al., 2023; Schwabish, 2021; Mitchell, Deckard, 2025), and each visualization should be based on reliable and verified data. Transparent presentation of sources minimizes the risk of greenwashing and strengthens stakeholder trust (Deloitte, 2024). Visualizations should also tell a story—guide the recipient through data and emphasize main conclusions (Brehmer, Kosara, 2021; Kernbach et al., 2015). Accessibility is gaining increasing importance, i.e., designing according to usability and inclusiveness standards (Strantz, 2021).

In summary, effective data visualization in business is based on four principles: simplicity, adaptation, accessibility, and narrativity. Their consistent application not only increases recipient understanding and engagement, but also strengthens the credibility and strategic effectiveness of corporate communication.

2.3. Data visualization strategies

Data visualization strategies can be divided into three main approaches: informational, narrative, and emotional. Each serves different communication purposes—from conveying knowledge and supporting decisions to engaging and evoking emotions.

Informational visualizations focus on transparency, accuracy, and effective data transmission. They use classic forms, such as bar charts, line graphs, or scatter plots, selected according to data type and recipient knowledge level. The goal is maximum comprehensibility and ability to compare information. Although they support the decision-making process and memorization, they often lack an emotional component (Mildau et al., 2024; Garretón et al., 2023). In relation to ESG reports, informational visualization ensures comparability of ESG indicators between periods and entities (Yadav, 2025). Primarily charts, tables, and infographics are used here, which support report readability and its control function. The goal is to legitimize company actions through numbers, i.e., showing progress in emission reduction, energy consumption, or improvement of working conditions.

Narrative visualizations combine data with story elements, guiding the recipient through a logically structured message. They use sequence, flow, and interactivity to give data meaning and context. Typical of journalism and education, they foster engagement and deeper understanding (Segel, Heer, 2010; Sakarang et al., 2025). ESG reports use storytelling elements here—photos, quotes, descriptions of social initiatives, to give data human meaning. The goal is to build trust and emotional connection with the recipient by showing that numbers stand behind real actions and values (Degreef, 2024).

Emotional visualizations aim to evoke an affective reaction and shape attitudes. Through color, metaphor, and visual forms, they can strengthen trust, memorization, and persuasion. Research indicates that emotion-based visualizations have a stronger impact than illustrations and more effectively engage recipients, especially when combined with narrative (Garretón et al., 2023; Blair et al., 2024). As Degreef (2024) notes, aesthetics, color schemes, and iconography (e.g., green, nature, people) can shape the perception of a company as ethical and pro-ecological regardless of actual results.

Effective visual communication requires a balance between clarity, narrativity, and emotional impact. In practice, most ESG reports combine elements of all three strategies. As Deloitte (2024) indicates, mature reporting is based on a balance between data credibility (informational strategy), narrative authenticity (narrative strategy), and visual attractiveness (emotional strategy). Integration of these approaches allows creating a coherent message that

is simultaneously understandable, engaging, and compliant with formal ESG reporting requirements (Yadav, 2025).

Data visualization is a key element of an effective communication strategy, enabling quick understanding of complex information and supporting decision-making processes. Their importance grows in an environment of information overload, where simplicity, transparency, and attractive form become conditions for effective message delivery. Data visualizations allow recipients to see patterns, trends, and dependencies that would be difficult to identify in raw numerical compilations. Their effectiveness depends on adapting the form to the communication goal, recipients' knowledge level, and socio-cultural context (Franconeri et al., 2021; Ofori et al., 2025).

Effective visualization requires several essential elements. First, adaptation to the recipient—both in terms of graphic form selection and data detail level (Franconeri et al., 2021; Schwabish, 2021). Second, clear communication goal, as different types of visualization support memorization, and others—attitude or behavior change (Ancker et al., 2023). Third, design consistent with perception principles, which includes using Gestalt principles, avoiding cognitive overload, and using familiar graphic patterns (Midway, 2020). Finally, ethics and credibility are extremely important, because transparency and reliability in data presentation build trust and legitimize the message (Mathaisel, 2024).

2.4. Research gaps and study positioning

The existing research on visual communication in corporate and ESG reporting establishes that visual elements are strategic and purposeful, not merely decorative, serving functions like legitimacy building and impression management (Preston et al., 1996; Graves et al., 1996; Hrasky, 2012). Foundational work documented systematic patterns of visual manipulation, including measurement distortion and selectivity bias favoring positive performance data in both annual reports and sustainability reports (Beattie, Jones, 2000, 2008; Jones, 2011). Visual elements are also key mechanisms in greenwashing, featuring in tactics like using rhetoric without substance or selective emphasis (Lyon, Montgomery, 2015; Delmas, Burbano, 2011; Cho et al., 2012), and they interact dynamically with textual content to construct organizational narratives (Davison, 2007, 2015). Despite these insights confirming visual elements' role in strategic functions and potential manipulation.

The literature review reveals several important gaps that limit comprehensive understanding of ESG visualization strategies and their effectiveness across different contexts. These gaps provide the foundation and justification for the present study's approach and contribution.

Existing research focuses predominantly on Anglo-American or Western European contexts, particularly the United Kingdom, United States, and Australia. Central and Eastern European reporting practices remain significantly under-studied, despite these regions experiencing rapid regulatory transformation through EU directives such as CSRD and representing distinct institutional, cultural, and market contexts. The Polish retail sector,

operating under evolving regulatory requirements while serving increasingly sustainability-conscious consumers, represents an important yet under-examined case for understanding ESG visualization practices.

While existing studies examine corporate reporting broadly or focus on heavy industry and extractive sectors, few systematically investigate how sector-specific ESG challenges, stakeholder expectations, and operational characteristics shape visualization strategies. The retail sector presents distinctive characteristics—direct consumer relationships, complex global supply chains, visible sustainability impacts, and strong reputation sensitivity—that warrant dedicated analysis of how these factors influence visual communication approaches.

Most existing studies examine isolated visual elements—graphs, photographs, or specific design features—rather than analyzing holistic visualization strategies that integrate multiple elements. Understanding how companies strategically combine informational, narrative, and emotional visualization approaches, and how different visual components work together to create coherent sustainability narratives, requires more comprehensive analytical frameworks than currently dominate the literature.

Few studies employ systematic comparative approaches within specific sectors to identify patterns related to organizational characteristics such as size, ownership structure, market position, or actual sustainability performance. Comparative analysis is essential for distinguishing between industry-wide visualization conventions and company-specific strategic choices, and for understanding what factors drive variation in visualization quality and approaches.

Research often applies single theoretical lenses—either legitimacy theory, impression management theory, or stakeholder theory—rather than developing integrated frameworks that recognize the multiple simultaneous functions of ESG visualization. Visual communication in sustainability reports serves informational, persuasive, aesthetic, and strategic purposes concurrently, requiring theoretical approaches that can accommodate this complexity rather than privileging one dimension over others.

Much existing research predates recent mandatory ESG disclosure regulations, particularly the EU's CSRD directive that significantly transforms reporting requirements and standardization. Understanding how regulatory mandates shape visualization practices, quality, and strategic approaches requires analysis conducted under contemporary regulatory frameworks rather than relying primarily on findings from voluntary reporting contexts.

This study addresses these gaps through systematic, multi-dimensional comparative analysis of contemporary ESG visualization strategies in the Polish retail sector. By examining reports produced under CSRD requirements, employing integrated analytical frameworks combining visual rhetoric, semiotic analysis, and information design perspectives, and conducting within-sector comparisons to identify patterns and variations, this research contributes to more comprehensive understanding of ESG visualization as a strategic communication practice shaped by regulatory, sectoral, and organizational factors.

3. Methodology

3.1. Research design

This study employs an exploratory multiple case study approach (Yin, 2018; Eisenhardt, 1989) to investigate ESG visualization strategies across three Polish retail leaders. Case studies are appropriate when research questions focus on "how" and "why" phenomena occur, researchers cannot manipulate events, context is crucial, and boundaries between phenomenon and context are unclear (Yin, 2018).

We employ replication logic rather than sampling logic. Each case serves as an independent "experiment" testing whether patterns observed in one case appear in others (literal replication) or whether predictable differences emerge based on theoretical expectations (theoretical replication). With three cases, we can identify patterns common across all cases (suggesting sector-level norms), systematic differences related to organizational characteristics (suggesting contextual influences), and unique approaches warranting further investigation.

This study adopts an exploratory, theory-building approach rather than hypothesis testing. While we anticipate certain patterns based on organizational characteristics, we remain open to unexpected findings and emergent themes. Exploratory design enables discovery of unanticipated patterns, inductive theory development, flexibility, rich contextualized understanding, and avoidance of confirmation bias.

3.2. Case selection

This study analyzed three retail chains: Lidl (Lidl Sp. z o.o. sp. k.), Biedronka (Jerónimo Martins Polska S.A.), and Żabka (Żabka Polska S.A.). These companies represent key players in the Polish market but differ significantly in terms of business model, ownership structure, and ESG reporting maturity level. This sample selection allows for an in-depth comparison of ESG visualization strategies in the reports of companies with distinct organizational identities and market conditions.

Lidl Polska is one of the leading retail entities in the country, operating since 2002 as part of the international Schwarz Group (PAP Biznes, 2025a). The chain has over 950 stores served by 13 distribution centers and employs approximately 29,000 employees. In 2025, the company announced the creation of additional locations and investments worth approximately PLN 2 billion, covering logistics development and the implementation of pro-ecological solutions (Bankier.pl, 2025; PAP Biznes, 2025b).

Lidl's operations are based on an efficient discount model - low prices, high quality, and simplicity of assortment - combined with advanced logistics solutions and partnership cooperation with Polish suppliers, numbering over 850 (Poradnik Handlowca, 2025). The company promotes products of domestic origin, supports the export of Polish food,

and was responsible for generating 11.4 billion PLN in added value for the economy in 2024 (ESG, Trends, 2025).

Lidl Polska implements a broad sustainable development strategy encompassing environmental, social, and ethical goals, aligned with the international CSR model for 2020-2025 (KimJestesmy.lidl.pl, 2022). It collaborates with WWF Poland Foundation on biodiversity protection, implements the REset Plastic program aimed at reducing plastic consumption by 30% by 2025, and invests in the energy efficiency of retail facilities (Gazeta Prawna, 2025). Additionally, the company consistently increases wages and employment - in 2025, it allocated 200 million PLN for salary increases and new jobs (PAP Biznes, 2025b).

Biedronka, owned by the Portuguese Jeronimo Martins Group, is the largest retail chain in Poland, developing continuously since 1995. In 2025, the network comprises over 3800 stores in more than 1300 localities, served by 17 distribution centers and employing over 84.000 employees (Odpowiedzialna Biedronka, 2024; Onas.Biedronka.pl, 2025). Every day, its stores are visited by approximately 5 million customers, confirming its status as the undisputed leader of the Polish retail market (Money.pl, 2025; Wiadomości Spożywcze, 2025).

Biedronka's business model combines price accessibility with dynamic development of private labels (over 500 new products introduced in 2024) and close cooperation with local suppliers - 94% of food products in the offering come from Polish producers (Odpowiedzialna Biedronka, 2024). In financial terms, Biedronka accounts for nearly 71% of the entire Jeronimo Martins Group's revenue, generating 12.4 billion euros in revenue in the first half of 2025 and an EBITDA margin of 7.7% (Wiadomości Handlowe, 2025; Bankier.pl, 2025).

The chain consistently develops its ESG and sustainable development strategy through investments in photovoltaics (1695 stores with panels in 2024), plastic reduction (1219 tons less annually), greenhouse gas emission reduction (-18.5%), and activities supporting biodiversity and circular economy (Raport ESG Biedronka, 2024). Biedronka implements the slogan "Because the future has a future," integrating environmental, social, and economic responsibility as equal elements of its corporate identity (Media.Biedronka.pl, 2024).

Żabka is the largest convenience store chain in Poland (and a dynamically growing retailer in the region), which at the end of June 2025 had 11.793 locations in Poland and Romania - with the vast majority operating in a franchise format (Bankier.pl, 2025; Żabka Group, 2025). Żabka's business model is based on support and partnership relations with franchisees and a system of modern logistics and digital solutions (Żabka Raport, 2025; Business Insider, 2023). The chain continuously expands its convenience ecosystem offering, investing in automated formats (Żabka Nano), development of digital services, and AI technologies supporting operational decisions (Żabka Group, 2025; Żabka Group, 2024).

Żabka is a leader in implementing an advanced ESG strategy - for the third consecutive year, it has achieved the highest ranking scores (EcoVadis, Sustainalytics), and its Annual Report for 2024 was prepared according to CSRD directive requirements (PAP MediaRoom, 2025; ESG Trends, 2024). The chain significantly reduces GHG emissions (-31% y/y), reduces

the share of primary plastic, and the sales value of private labels supporting a sustainable lifestyle reached PLN 1.8 billion in 2024 (GF24, 2025; PAP MediaRoom, 2025). Table 1 presents the basic characteristics of the analyzed companies.

Table 1.

Main characteristics of Lidl, Biedronka, and Żabka stores

Category	Lidl	Biedronka	Żabka
Business model	International discounter (Schwarz Group)	Portuguese discounter (Jerónimo Martins)	Convenience chain (franchise)
Positioning	Cheaper shopping, better quality	Price leader	Convenience and proximity
Number of stores in Poland	approx. 950	approx. 3800	approx. 12.000
Target group	Families, conscious consumers	Mass market, price-sensitive customers	Young urbanites, impulse shopping
Capital and cultural context	Germany (reporting culture)	Portugal (JM group)	Poland (CVC Capital Partners)
ESG maturity	Very high (influence of German regulations)	High (stock exchange requirements in Portugal)	Medium, growing (local brand)
Mission	Our mission is to provide our customers with high-quality products at low prices	Biedronka offers carefully selected products of the highest quality at consistently low prices	Żabka Group's mission is to create value by simplifying people's lives

Source: own work based on: Żabka Group (2024). Raport roczny 2024; Onas.Biedronka.pl. (2025); KimJestesmy.lidl.pl. (2022).

3.3. Data sources

The study employs both primary and secondary data sources to enable comprehensive analysis of sustainability reporting practices while maintaining methodological rigor appropriate for a comparative case study design.

The primary data consists of the most recent published ESG/sustainability reports in Polish from each of the three companies, specifically the 2023 or 2024 editions depending on availability at the time of data collection. The decision to analyze Polish-language reports exclusively is grounded in several methodological and theoretical considerations. First, these reports represent the companies' primary communication channel with their core Polish stakeholders, including employees, local communities, Polish consumers, regulatory bodies, and domestic investors. Second, this approach aligns with the study's focus on how multinational and domestic companies construct and communicate sustainability legitimacy within the specific institutional and cultural context of the Polish market. Third, analyzing reports in a single language ensures consistency in interpretation and avoids complications arising from translation differences or strategic variations between Polish and international versions of reports.

Secondary data sources provide essential context for interpreting primary data and include: company background information from corporate websites and press releases; industry reports on the Polish retail sector and its sustainability challenges; ESG rating assessments and

benchmarks from recognized agencies; academic literature on sustainability reporting, discourse analysis, and legitimacy theory; and trade press articles covering the studied companies' sustainability initiatives. These sources enable triangulation of findings and situate the analysis within broader industry and theoretical contexts.

3.4. Analytical framework

Analysis proceeds systematically across four interrelated dimensions, integrating quantitative measurement with qualitative interpretation to build a comprehensive understanding of how organizations deploy visual communication in sustainability reporting. This multi-dimensional approach captures both the technical characteristics of visual elements and their broader strategic and semiotic functions.

The framework begins with foundational analysis through structure and scope (Dimension 1) and visualization inventory (Dimension 2). The structural dimension establishes baseline characteristics including total page count, visualization density, text-visual ratio, and section structure. Building on this foundation, the inventory systematically catalogues all visual elements using a comprehensive classification scheme that includes charts (bar, line, pie, histogram, scatter), tables (numerical, textual), infographics, photographs, maps, illustrations, icons and pictograms (symbols, storytelling elements), logos, and other graphic elements. This detailed taxonomy enables systematic tracking of visual diversity and patterns across the corpus, providing a quantitative profile of visual communication intensity and variety.

Semiotic analysis (Dimension 3) interprets meaning-making processes for exemplary visualizations through a systematic procedure that moves from sign inventory through multiple levels of interpretation. Analysis begins by cataloguing all visible elements and notable absences, then identifies signifiers and signifieds before examining both denotative (literal) and connotative (cultural, emotional) meanings. The procedure advances to decode cultural conventions and myths that naturalize particular values and power relations, examines paradigmatic choices (what was selected over alternatives) and syntagmatic relationships (how elements combine to create meaning), and contextualizes findings within historical, cultural, and organizational settings.

This multilayered approach reveals how organizations leverage visual semiotics to shape stakeholder interpretation and construct particular narratives about sustainability performance.

The framework then addresses functional intent and quality through communicative functions (Dimension 4). Functional analysis identifies the primary communicative intent behind visualizations, coding each for its dominant purpose: informational (presenting factual data), comparative (enabling performance assessment), narrative (telling stories, showing processes), interpretive (explaining context or methodology), emotional (building connection, demonstrating values), or persuasive (convincing of commitment or leadership).

3.5. Quality and rigor

Research quality was ensured through systematic application of trustworthiness criteria appropriate for qualitative research, addressing credibility, transferability, dependability, and confirmability throughout the analytical process. These criteria provide a comprehensive framework for establishing rigor while recognizing the interpretive nature of semiotic and qualitative analysis.

Credibility was established through multiple strategies that strengthen confidence in findings. Thick description provided rich, detailed accounts of visual communication practices within each case, enabling readers to assess the adequacy of interpretations. Triangulation operated across multiple data sources (reports, organizational documents, contextual materials) and analytical perspectives (quantitative inventories, semiotic interpretation, strategic analysis), allowing convergence of evidence from different vantage points. Extended engagement with each case enabled deep familiarity with organizational visual communication strategies, while a consensus coding approach for interpretive dimensions reduced individual bias and enhanced inter-subjective agreement.

Transferability and dependability were addressed through comprehensive documentation and systematic procedures. Transferability was enhanced by providing detailed case descriptions that allow readers to assess applicability to their contexts, clearly specifying study boundaries and scope, employing analytical rather than statistical generalization to extend insights beyond the immediate sample, and documenting variation across cases to illuminate contextual factors shaping visual communication choices. Dependability was ensured through a detailed analytical protocol that standardized procedures across cases, systematic documentation of all analytical decisions and processes, and consistency checks to verify that the framework was applied uniformly.

Finally, confirmability was maintained through practices that enhance objectivity and guard against predetermined conclusions. All interpretations remained grounded in documented evidence from the reports themselves, with claims traceable to specific visual elements and textual content. Reflexivity about the researcher's perspective, background, and potential biases was maintained throughout analysis, acknowledging how these might shape interpretation. Alternative explanations for observed patterns were actively considered and evaluated against evidence. Negative case analysis identified instances that contradicted emerging patterns, either refining interpretations or acknowledging genuine variation rather than forcing all cases into predetermined categories.

3.6. Study Limitations

This study is subject to several limitations that qualify the scope and generalizability of findings, relating to sample characteristics, methodological constraints, and analytical boundaries. Acknowledging these limitations is essential for appropriate interpretation and application of results.

Sample and scope limitations constrain the breadth of insights. The small sample size of three cases enables rich, in-depth analysis but limits the range of visual communication strategies captured and the ability to identify comprehensive patterns across the retail sector. Sectoral focus on retail means that findings reflect characteristics of this industry - with its emphasis on consumer relationships, brand identity, and stakeholder visibility - and may not transfer directly to industries with different reporting pressures, stakeholder configurations, or communication norms. The temporal snapshot approach, analyzing single-year reports, captures current practices but cannot reveal how visual communication strategies evolve over time in response to changing regulations, stakeholder expectations, or organizational learning. Geographic specificity to the Polish context introduces cultural, regulatory, and market factors that differ from other regions, potentially limiting transferability to organizations operating under different institutional conditions.

Methodological limitations arise from data sources and analytical approaches. Analysis is restricted to published reports, which represent carefully curated organizational communication rather than internal deliberations, discarded alternatives, or the full range of sustainability activities. This data source limitation means the study examines official organizational self-presentation rather than actual performance or decision-making processes. Qualitative semiotic analysis inherently involves researcher interpretation and judgment, introducing subjectivity even when systematic procedures and credibility measures are employed. Language considerations are also important - analyzing reports originally published in Polish while writing the research article in English introduce potential issues of translation, cultural nuance, and linguistic framing that may affect interpretation.

Finally, perspective and inference limitations shape what can be concluded from findings. The study analyzes the producer perspective - what organizations communicate and how - but does not incorporate the receiver perspective of how stakeholders actually interpret, use, or respond to visual communication in reports. Publication bias is inherent in self-published sustainability reports, which organizations use strategically to manage reputation and may selectively emphasize positive information while downplaying challenges or failures. The case study methodology reveals associations and patterns but cannot definitively establish causality, observed relationships between organizational characteristics and visual communication strategies are suggestive rather than conclusive, as multiple factors operate simultaneously and experimental control is impossible in naturalistic organizational settings.

4. Resultants

4.1. Case 1: Lidl Polska

4.1.1. *Report Structural Profile*

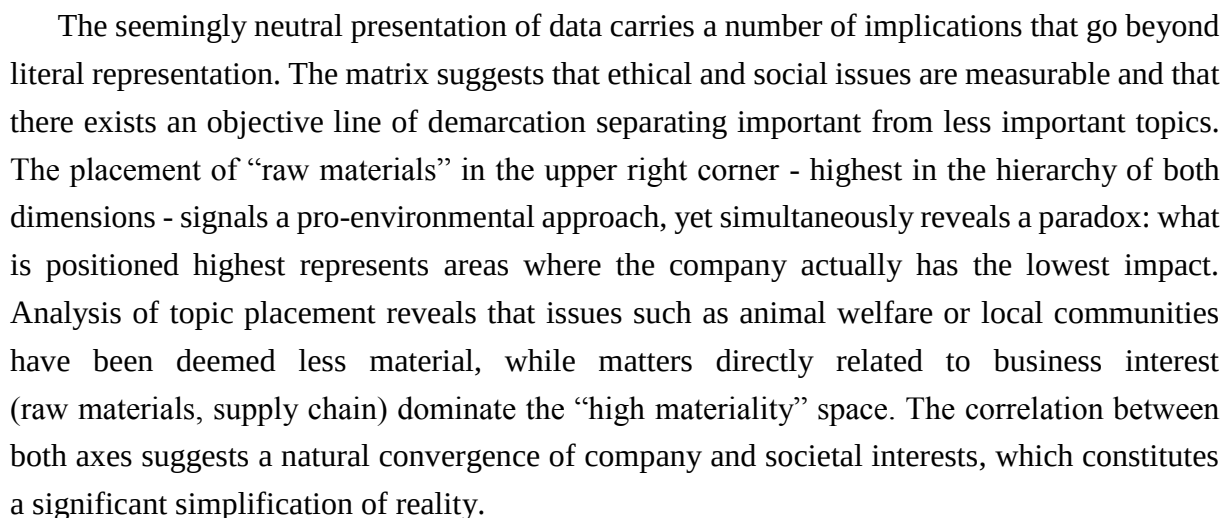
The Lidl Polska sustainability report comprises 141 pages organized into nine thematic sections. The document opens with foundational elements including a CEO letter, company information, responsible business strategy, materiality analysis, and goal progress tracking. The core content structures around five sustainability pillars: Climate Protection (limiting warming to 1.5°C), Biodiversity Respect (ecosystem preservation), Resource Protection (subdivided into raw materials, circular economy, food waste prevention, and water conservation), Fair Operations (with six subsections covering employment, wages, business relations, diversity, animal welfare, and corporate citizenship), and Health Promotion (conscious nutrition). The report concludes with stakeholder engagement dialogue, responsible products, and methodological information. This architecture reflects strategic emphasis on environmental and social governance integration with particular attention to supply chain responsibility and stakeholder inclusivity.

4.1.2. *Typological distribution*

The report contains 287 visual elements across 141 pages, yielding 2.04 elements per page. Photographs dominate with 90 instances (31.4%), indicating preference for authentic, representational employees, stakeholders, products and sustainability initiatives pictures. Icons and pictograms provide 65 instances (22.6%), serving as efficient symbolic communication for processes and concepts. Other graphic elements contribute 47 instances (16.4%), while illustrations add 27 instances (9.4%). Logos appear 23 times (8.0%), infographics 20 times (7.0%), and tables 14 times (4.9%). Remarkably, charts appear only once (0.3%), indicating near-absence of conventional data visualization. Maps are completely absent. This profile reveals a photography-dominant strategy privileging authentic imagery and symbolic representation over quantitative visualization.

4.1.3. *Semiotic analysis of exemplars*

The subject of analysis is a graphic representation of a materiality matrix, consisting of a two-dimensional coordinate system containing 17 topics related to Corporate Social Responsibility (Figure 1). The vertical axis represents “business significance” (scale 0-10), while the horizontal axis indicates “impact materiality” (also 0-10). The central element of the composition is a blue curve connecting points in the 7-9 range, which divides the space into two areas. Individual topics are represented by icons containing simple symbols in circles on colored backgrounds - 9 are located below the line, 8 above. The color palette includes five groups: dark green (5 icons), olive (3), light blue (3), dark blue (3), and dark gold (3). The whole is accompanied by a title on a green-olive background and the marking [GRI 3-2], indicating compliance with Global Reporting Initiative standards.



The matrix naturalizes a series of ideological assumptions characteristic of contemporary corporate capitalism. First, the presentation of social and environmental issues as measurable and mappable on a two-dimensional scale suggests that ethics can be quantified and subjected to rational management - this is the myth of ethics objectification. Second, the visualization reinforces the belief that enterprises possess the power to effectively solve social and environmental problems, while simultaneously omitting the fact that they are often their source. The most striking discovery is the disproportion in the perception of materiality - topics placed above level 9 show that how the environment affects business is treated as more than four times more important than business's impact on the environment, revealing the actual primacy of corporate interest. Additionally, the static character of the matrix suggests that ESG priorities are stable and can be planned in advance, ignoring the dynamic nature of social and environmental challenges.

The sequence of elements and their spatial relationships create a coherent narrative. The upper right corner as the “highest” and “furthest advanced” place functions culturally as a space of success and progress. The arrangement of icons creates a visual hierarchy that guides the viewer's eye from “less material” social issues toward “key” business matters. The presence of paratextual elements (title, footnote, GRI marking) gives the matrix an appearance of scientific credibility and professionalism. The correlation between axes - with few exceptions - reinforces the impression of natural harmony between business objectives and social responsibility.

The matrix functions within the context of CSRD directive requirements and GRI standards, which defines its formal audience - auditors, ESG analysts, and informed stakeholders familiar with reporting methodology. For the average reader, the document remains seemingly readable, yet its semantic complexity may mislead, suggesting actual actions rather than an analysis of topic materiality.

Semiotic analysis reveals a fundamental contradiction between the tool's declared function (objective assessment of topic materiality) and its actual operation as an instrument for legitimizing corporate priorities. The matrix, operating through the language of objectivity and international standards, naturalizes a worldview in which the enterprise's interest remains paramount over social and environmental issues, while simultaneously masking this hierarchy through the neutral language of metrics and professional data visualization.

The another object of analysis presents a photographic portrait of a young African woman in traditional attire, holding a large wicker basket filled with ripe cacao fruits (Figure 2). The composition is based on a medium portrait shot with direct eye contact, which builds an intimate relationship with the viewer. The background - blurred greens and browns suggesting tropical vegetation - concentrates attention on the figure and the exposed basket.



Figure 2. Photography – resource protection.

Source: Lidl Polska. Raport, p. 56.

The color scheme of the image creates a coherent narrative about harmony with nature. The dominant browns, beiges, oranges, and yellows - both in the woman's attire and in the cacao fruits - symbolize earth, maturity, and warmth. Characteristic is the deliberate omission of green in the clothing, which emphasizes the connection with the final product rather than with the plantation itself. The yellow-and-white headscarf and wicker basket function as signs of traditionalism and authenticity, signaling distance from modern civilization. The absence of machines, plastic, or contemporary devices reinforces the impression of temporal suspension.

Particularly significant is the woman's radiant, genuine smile - constructed as an expression of pride in her work, satisfaction, and contentment with her situation. Combined with her weathered hands, this creates a narrative about dignified, satisfying work close to nature.

The image activates several overlapping cultural codes. It evokes the convention of National Geographic photography - an aestheticized representation of “authentic” Africa, where tradition and nature remain untouched by modernization. This aligns with the “noble savage” trope - a figure living in harmony with nature, in their proper place, unburdened by civilizational progress. The Arcadian idyll is complemented by the fair trade code, signaling an equitable economic model not based on exploitation.

At the deepest level, the photograph naturalizes a series of ideological beliefs. It promotes the myth of fair capitalism, which allegedly leads to global prosperity while leaving traditional production structures intact. Simultaneously, it perpetuates the notion of Africa's technological backwardness as a natural and desirable state - tradition becomes a value in itself rather than an effect of structural inequalities.

The image reinforces postcolonial power relations: Europe/the West remains the consumer, Africa the supplier of raw materials, with this relationship presented as mutually beneficial. The woman as guardian of tradition and natural producer fits into a broader narrative about

simple living as the source of happiness, which justifies maintaining the status quo in the global value chain.

The photograph is addressed to the Polish middle class - environmentally conscious consumers seeking authentic, ethically sourced products. The promise of certification and support for small-scale farmers is meant to legitimize the act of consumption as an ethical choice, though it simultaneously maintains asymmetric economic relations. Paradoxically, the emancipatory rhetoric of fair trade coexists here with the perpetuation of imaginaries of Africa as a pre-modern space, locked in the eternal present of tradition.

4.1.4. Functional profile

Functional analysis reveals 340 total functional instances across six categories. Informational functions lead with 115 instances, distributed across icons (38), logos (23), infographics and photographs (16 each), and tables (14). Emotional functions nearly match with 116 instances, dominated by photographs (62) and logos (23), indicating deliberate balance between rational disclosure and affective engagement. Persuasive functions appear 56 times, concentrated in logos and icons (23 and 18 respectively). Narrative functions contribute 24 instances, spread across illustrations and icons (7 each). Comparative functions appear minimally with 16 instances, while interpretive functions provide 13 instances. The near-perfect balance between emotional and informational functions represents the report's core architecture: equal investment in accountability and affective connection. Photographs serve primarily emotional purposes (68.9% of all photos), while icons function as informational workhorses. The minimal comparative and interpretive functions suggest confidence that emotional authenticity and factual transparency together constitute sufficient grounds for stakeholder trust.

4.2. Case 2: Biedronka

4.2.1. Report Structural Profile

The Biedronka sustainability report comprises 131 pages organized into six streamlined sections. Opening with management letters and organizational context, the substantive content structures around three thematic pillars: environmental stewardship (caring for the environment), stakeholder relations (building responsible relationships), and corporate governance (managing responsibly). The report concludes with methodological transparency about reporting practices. This simplified, stakeholder-friendly architecture prioritizes thematic clarity over exhaustive categorization, reflecting accessibility-oriented communication philosophy. The tripartite substantive framework aligns with conventional ESG paradigms while maintaining organizational simplicity suitable for broad audience engagement.

4.2.2. Typological distribution

The report contains 469 visual elements across 131 pages, yielding exceptionally high density of 3.58 elements per page. Other graphic elements overwhelmingly dominate with 218 instances (46.5%), encompassing mainly navigational elements, decorative borders and design elements. Photographs provide 103 instances (22.0%), serving as primary representational content. Icons and pictograms contribute 47 instances (10.0%), infographics 31 (6.6%), logos 26 (5.5%), tables 22 (4.7%), and illustrations 20 (4.3%). Charts appear only once (0.2%), while maps appear once as well. This profile reveals design-intensive, graphically elaborate approach fundamentally distinct from photography-dominant strategies, prioritizing visual branding, aesthetic appeal, and design cohesion as primary communication values.

4.2.3. Semiotic analysis exemplars

The subject of analysis is a timeline presenting the chronology of a thirty-year period of Biedronka's operations in Poland, covering the years 1995-2019 (Figure 3). This visual artifact presents not only the commercial milestones of the enterprise but, above all, exposes the evolution of activities in the area of corporate social responsibility. The composition is based on a linear narrative structure, constructed through red arrows made of dashed dots that guide the viewer's eye and impose a specific reading direction.



Figure 3. Infographic Commemorating Biedronka's 30th Anniversary in Poland.

Source: Raport zrównoważonego rozwoju sieci Biedronka, p. 8.

The dominant element is the title in capital letters using a large, black font, while the date 1995 stands out with an enlarged, red, decorative typography - signaling the starting point of a success narrative. The remaining eleven dates are presented in a unified, simple font, creating a coherent visual rhythm. The white background and numerous empty spaces give the whole clarity and lightness, while the even distribution of three groups of red and yellow quadrilaterals - resembling confetti in corporate colors - introduces an atmosphere of celebration. The composition includes four logos (Caritas, the joint logo of Biedronka and PZPN, Clean

Tatras, Biedronka Health Academy) and four illustrations presenting selected initiatives (a competition, the Fresh Gang, a Go Bio brand product, the Good Bag).

At the denotational level, we are dealing with a simple chronological juxtaposition of events from the company's history. However, the true meaning is revealed at the connotational level. Red - the color of blood and energy - becomes a symbol of the brand's passion, dynamism, and determination. Partnerships with institutions such as Caritas connote Christian values of mercy, while cooperation with PZPN refers to Polishness, patriotism, and community around the national sport. Individual initiatives build a multi-layered message: the Fresh Gang represents family values and care for the health of the younger generation, bio products signal ecological awareness and middle-class aspirations, the Good Bag symbolizes the fight against waste, and the Clean Tatras project combines ecological responsibility with local Polish patriotism.

The artifact operates with a set of recognizable cultural codes: legitimization through partnership with recognized Polish institutions, moral business based on caring for the weak, and the traditional Polish family as a social foundation. Health, sport, and education are constructed as fundamental values that the corporation actively promotes and supports. The analysis reveals a series of myths embedded in the visual narrative. Central is the myth of Biedronka's Polishness - a Portuguese company manifests itself as an enterprise deeply rooted in Polish culture, operating a polycentrism strategy. Another myth is corporate paternalism: Biedronka not only sells products but educates and trains consumers, cares for their health, promotes ecology and family values.

The myth of corporate altruism also emerges, which naturalizes the belief that CSR activities stem from authentic care rather than tax or image calculations. The idea that responsibility for social assistance is shifting from the state to the consumer cooperating with the corporation is also implicitly promoted. Paradigmatic analysis reveals what was deliberately omitted. The absence of people - both employees and customers - leads to depersonalization; it is the idea that counts, not the person. There is no mention of the company's Portuguese origin, failed local shops, competition, or crises. History is presented as a linear success story. Also absent are elements typical of discount stores: promotions, lowest prices, basic (often unhealthy) products - the company escapes pigeonholing as a cheap store.

The sequential nature of the timeline creates a progressive narrative: as time passes, especially after 2006, the number of social initiatives grows, suggesting an evolution of image - from a purely commercial company to a socially responsible organization engaged in community life. The whole is directed at an idealized recipient: a traditional Polish family, religious, patriotic, identifying with the national team, ecologically aware, but also socially diverse - both in need of help and capable of sharing with others. This is the average Pole whose values the company declares to share and promote.

The analyzed infographic is an example of an advanced corporate image-building strategy, where a foreign company adapts to the local cultural context through consistent communication of values considered genuinely Polish. Semiotic analysis reveals the ideological work of the sign: the naturalization of a paternalistic model of the corporation as an educational and caring institution that supplements - and perhaps replaces - the traditional functions of the state and other social institutions.

The other subject of this analysis is an advertising infographic from the Biedronka retail chain, part of an employer branding campaign (Figure 4). The graphic presents data about employee diversity on a black background, with the centrally placed slogan “RóżniMY. tworzymy Biedronkę” (We’re Different. We create Biedronka) and seven colorful circles containing statistics about the workforce composition.



Figure 4. Advertising infographic – “RóżniMY”.

Source: Raport zrównoważonego rozwoju sieci Biedronka, p. 63.

At the literal level, the infographic presents numerical data about the company's employees: 84 thousand people employed, 1300 people with disabilities, 500 self-checkout assistants, 40 nationalities, 4 generations, an average age of 39, and 67% parents in the workforce. The composition uses diverse graphic forms - circles in various sizes and pastel colors, decorative elements such as streamers, sparkles and triangles, yellow lines symbolizing energy, and different types of fonts, including handwriting. The minimalist design abandons photographs or illustrations of human figures in favor of abstract geometric forms.

Connotative analysis reveals a rich layer of cultural meanings. The slogan “RóżniMY” operates as a play on words, combining the adjective “różni” (different) with the pronoun “my” (we), which builds a narrative about a community based precisely on diversity. The word “tworzymy” (we create) suggests active employee participation in shaping the organization, going beyond the traditional employer-employee relationship and implying co-authorship of the company's success. Visual diversity - colors, shapes, fonts - constitutes a direct metaphor for human diversity, where each element is different but co-creates a cohesive whole.

Pastel colors evoke warmth and openness while simultaneously giving the message a light, almost playful character. Deliberately uneven, imperfect circles can be read as a message about accepting imperfection - a suggestion that “we're not perfect and we're fine with that”. The black background serves as a uniform surface on which diversity becomes more visible, creating a dynamic contrast between uniformity and differentiation. The emotional code of the graphic operates on positive associations - streamers and balloons evoke a celebratory atmosphere, while dynamic yellow lines suggest energy, movement and optimism. The use of concrete numbers is meant to authenticate the message, building an impression of transparency and reliability in corporate communication.

At a deeper ideological level, the infographic naturalizes a series of beliefs characteristic of contemporary corporate discourse. It promotes the myth of work as a source of joy and self-realization, where diversity becomes a value in itself, independent of actual organizational practices. The modern design implies an equation: modernity equals progressiveness, which in turn equals moral value. The company presents itself as people-oriented, where everyone is equal and has the opportunity to co-create, which masks actual hierarchies and power structures.

However, what is crucial is the tension between declared values and strategic omissions. The graphic contains no information about the power structure within the organization - we don't know what diversity looks like in managerial and executive positions, whether the composition of management reflects the diversity of the workforce. The statement that employees “create” the company masks the hierarchical nature of an organization that is not, after all, a worker cooperative. There is also no information about the geographical origin of these 40 nationalities - is this global diversity, or is it limited to specific regions?

Particularly problematic is a mechanism that could be called disability-washing. The number of 1300 employees with disabilities, presented as proof of inclusivity and company success, may actually indicate non-fulfillment of the statutory obligation to employ 6% of people with disabilities, which with 84 thousand employees would mean the need to employ over 5000 people. Similarly, self-checkout machines are presented as an addition creating new jobs (500 assistants), not as a potential threat to traditional cashier positions. The graphic suggests that numbers ensure transparency, but it omits key information about working conditions, turnover, satisfaction, or employee engagement.

The fundamental omission is the complete absence of employees' own voices - it is the corporation speaking about them and for them, constructing an image consistent with its own image objectives. Compositional choices are significant in this context. The central placement of the slogan “RóżniMY” prioritizes the message about diversity as a fundamental brand value. The free, somewhat chaotic arrangement of elements suggests flexibility and lack of rigid structures, which is meant to correspond with the promise of an open, relaxed organizational culture. At the same time, the choice of abstract forms instead of photographs of actual employees may raise questions - would authentic diversity not be aesthetically pleasing enough

for the campaign's assumptions? Would it not risk violating the uniformity of the visual message?

Biedronka's infographic is a typical example of contemporary employer branding communication that appropriates progressive values of diversity and inclusivity for image and recruitment purposes. It operates through a code of positive emotions and modernity, while strategically omitting issues of power, actual working conditions, the real organizational structure, and the voices of those actually concerned. What we have here is diversity-washing - a facade presentation of commitment to diversity without actual transformation of corporate relations and decision-making structures. The graphic celebrates diversity as an aesthetic and marketing value, not as a foundation for democratizing the workplace.

4.2.4. Functional Profile

Functional analysis reveals 380 total instances. Informational functions dominate with 142 instances, led by photographs (37), icons (28), and logos (26), establishing factual credibility foundation. Emotional functions follow with 91 instances, concentrated in photographs (42) and logos (26), indicating substantial investment in affective engagement. Persuasive functions contribute 64 instances, with logos (26), photographs (15), and icons (9) advancing strategic advocacy. Comparative and interpretive functions share modest presence at 31 instances each, with tables driving comparison (12) and icons supporting interpretation (10). Narrative functions appear minimally with only 21 instances. The informational-emotional-persuasive triad suggests communication model recognizing sustainability credibility requires factual disclosure, emotional identification, and strategic persuasion. Photography serves dual informational-emotional purposes, while tables maintain concentrated informational-comparative neutrality. The minimal narrative investment indicates preference for thematic disclosure over chronological storytelling.

4.3. Case 3: Žabka

4.3.1. Report Structural Profile

The Žabka sustainability report comprises 67 pages organized into five sections with multiple subsections, reflecting technically sophisticated, regulation-oriented approach aligned with European Sustainability Reporting Standards (ESRS). Opening with selected ESG information, the report addresses sustainability reporting fundamentals including corporate governance and double materiality analysis. The environmental pillar subdivides into decarbonization, biodiversity, circularity, and EU Taxonomy alignment. Social issues structure around own workforce and consumers/end users. Corporate governance constitutes the fourth section. The extensive appendix incorporates disclosure requirements index and external assurance report. This regulation-driven architecture prioritizes systematic coverage of mandated areas, analytical rigor, and transparency through comprehensive indexing and third-party validation, positioning the report as technical reference document for sophisticated stakeholders.

4.3.2. Typological distribution

The report contains 395 visual elements across 67 pages, yielding extraordinarily high density of 5.89 elements per page. Icons and pictograms dominate with 107 instances (27.1%), indicating heavy reliance on symbolic communication for efficiency. Logos appear 76 times (19.2%), other graphic elements 80 times (20.3%), and tables 64 times (16.2%)—the highest table deployment across cases. Infographics contribute 31 instances (7.8%), while photographs provide only 27 (6.8%), illustrations 10 (2.5%). Charts and maps are completely absent (0%). This profile reveals strategy centered on symbolic efficiency, structured data presentation, and brand reinforcement while minimizing representational imagery and traditional analytical visualization. The table-heavy approach indicates commitment to systematic, verifiable data disclosure aligned with regulatory expectations.

4.3.3. Semiotic analysis of exemplars

The subject of analysis is an infographic presenting the ESG Framework Policy in the form of a conceptual circular graphic, maintained in the characteristic color scheme of greens, yellows, and oranges on a white background (Figure 5). The visual structure is based on five concentric rings that create a complex semiotic composition.

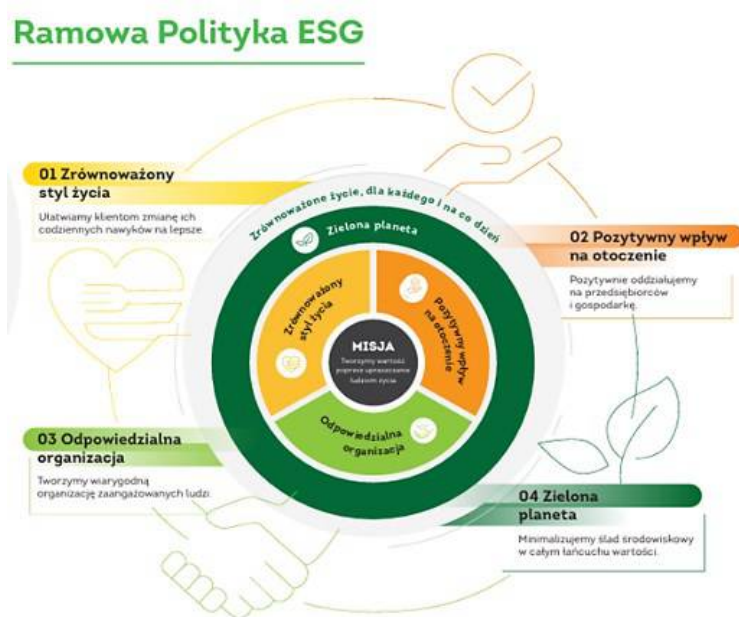


Figure 5. Infographic presenting the ESG Framework Policy.

Source: Raport roczny Żabka Group, p. 61.

The infographic is built around a centrally placed company mission, highlighted against a black background. The first ring contains three policy pillars: Sustainable Lifestyle, Positive Impact on the Environment, and Responsible Organization, presented in light green, orange and yellow. The second ring constitutes the fourth pillar - Green Planet - on a dark green background with white text. The third ring presents the policy result: “Sustainable Life for Everyone, Every Day” on a gray background with green text. The whole is surrounded by decorative

elements – text fields with icons in vibrant colors that extend beyond the main circle, creating a dynamic composition.

A key semantic element is the dominance of green color, which directly connotes ecology, nature, and environmental care. The circular structure suggests completeness, interdependence, and organic wholeness - it evokes associations with a tree trunk, where policy grows in successive rings from the central mission. The icons used, such as clasped hands, a leaf, a heart with a fork and knife, or a hand with a circle, reinforce the message of cooperation, health, transparency, and positive impact. Placing the mission in the center against a black background gives it the rank of the most important, unchanging, and stable element - the entire organization is built around it.

The even distribution of the first three pillars suggests their equivalence, while the fourth pillar - Green Planet - encompassing the others, appears as their overarching context or effect. It is characteristic that the policy result is the only element not explained in detail, which allows freedom of interpretation and builds an impression of openness. The graphic balance of the entire composition additionally reinforces the message about the organization's balanced policy.

The analysis reveals a series of encoded ideologies and cultural myths. The infographic naturalizes the belief that all elements are interconnected and mutually influence each other, promoting an organic - rather than mechanical - model of operation. The dominance of green can be read as a deliberate marketing technique, a form of greenwashing, intended to build the company's ecological image. A key myth is the central position of the organization's mission - it, not people or the environment, constitutes the reference point for the entire system.

The infographic also suggests that it is the consumer who bears responsibility for the planet, while the company merely supports these efforts, which can be interpreted as a shift of responsibility from the corporation to individuals. The slogan “Sustainable Life for Everyone, Every Day” promotes the belief that business knows better what we want and can shape our consumer habits. Other ideological assumptions are also reinforced: the myth of authentic employee engagement, the belief in the exclusively positive impact of business on the environment, and faith in the organization's credibility as an equal partner. The equivalence of the pillars proves to be only apparent - their hierarchical arrangement and differences in presentation suggest different priorities in corporate reality.

The simple, readable form indicates that the infographic is not intended for auditors or specialists - it lacks specific data and measurable goals. This is a message directed at the average recipient, intended to build trust through visual transparency and promises contained in slogans such as “we facilitate”, “we positively influence”, “we minimize”, or “we create”. It is a shallow yet strong and safe message that, through aesthetic coherence and symbolism of naturalness, legitimizes the organization's activities in the ESG area, while simultaneously concealing the complexity of actual power relations and responsibility, and shifting the burden of ecological responsibility from the corporation to consumers.

The another analyzed artifact is a tabular infographic presenting climate risks and opportunities for an enterprise, compliant with TCFD (Task Force on Climate-related Financial Disclosures) guidelines and the ERM risk management system (Figure 6). The infographic is characterized by clear compositional symmetry - the left side is dedicated to climate risks, while the right side focuses on opportunities. The left side is dominated by yellow (10 icons) and orange (1 icon) colors, while the right side features light blue (4 icons) and navy blue (3 icons). A contrasting white background enhances the readability of the message. Significantly, red and black colors, which symbolize extreme threats, are completely omitted. The structure consists of three columns: category, risk/opportunity description, and organizational response.

Ryzyka związane z klimatem		
Kategoria	Ryzyko	Nasza odpowiedź
Fizyczne /nagłe	Zagrożenia dla działalności na skutek nagłych zjawisk pogodowych	- Plany ciągłości działania, w tym zarządzanie łańcuchem dostaw, zapewniające możliwość dystrybucji do sklepów w sytuacjach awaryjnych. - Dywersyfikacja łańcucha dostaw. - Ubezpieczenie na wypadek wystąpienia krótkotrwałych czynników ryzyka.
	Zagrożenia dla działalności na skutek długotrwałej zmiany klimatu	- Plany i analizy adaptacyjne dotyczące wdrożenia odpowiednich rozwiązań technicznych i konstrukcyjnych. - Studium wykonalności w zakresie wybranych innowacji i technologii ułatwiających przystosowanie się do zmiany klimatu.
Fizyczne /długotrwałe	Ograniczenia/zakłócenia dostępności wody w łańcuchu dostaw	Plany ciągłości działania na wypadek niedoborów wody.
	Ograniczenia/zakłócenia zaopatrzenia w energię w łańcuchu dostaw	- Plany ciągłości działania na wypadek niedoborów energii elektrycznej. - Pozyskiwanie energii elektrycznej ze źródeł odnawialnych, potwierdzone otrzymanymi gwarancjami pochodzenia.
Przejścia /rynkowe	Dalszy wzrost cen energii	- Angażowanie interesariuszy w inicjatywy na rzecz ograniczenia zużycia energii. - Studium wykonalności dotyczące pozyskiwania energii elektrycznej z OZE na terenie obiektów należących do Żabki.
	Ograniczenia dostaw realizowanych za pomocą pojazdów z silnikami spalinowymi w centrach miast	- Dedykowane zasoby do analizy zmian legislacyjnych w obszarze ESG, w tym dotyczących ochrony klimatu, wprowadzenie odpowiednich wymogów w celu zapewnienia zgodności. - Wprowadzenie długoterminowej strategii logistycznej, w której zostaną określone szczegóły polityki transportowej.
Przejścia /polityczno-prawne	Zaostrzenie przepisów w obszarze zrównoważonego rolnictwa i wpływu pochodzenia surowców na naturalną bioróżnorodność	- Dedykowane zasoby do analizy zmian legislacyjnych w obszarze ESG, w tym dotyczących bioróżnorodności, wprowadzenie odpowiednich wymogów w celu zapewnienia zgodności. - Szczegółowa analiza wpływów i zależności w odniesieniu do zasobów naturalnych oraz opracowanie planu działań w zakresie bioróżnorodności.
	Dostosowywanie się do dynamicznie zmieniających się wymogów regulacyjnych w obszarze ESG, m.in. uzyskiwanie niezbędnych danych od pozostałych podmiotów w łańcuchu wartości	- Udoskonalenie praktyk w zakresie kontroli i raportowania w celu zwiększenia przejrzystości działań Grupy na rzecz ochrony klimatu. - Dedykowane zasoby do analizy zmian legislacyjnych w obszarze ESG, w tym dotyczących ochrony klimatu, wprowadzenie odpowiednich wymogów w celu zapewnienia zgodności.
Ocena ryzyka według systemu ERM: ■ Niskie ■ Średnie ■ Wysokie ■ Bardzo wysokie		
Szanse związane z klimatem		
Kategoria	Szansa	Nasza odpowiedź
Efektywne wykorzystanie zasobów	Zmniejszenie zużycia energii poprzez realizację inicjatyw proekologicznych	- Wdrażanie najbardziej efektywnych operacyjnie i finansowo rozwiązań pro-klimatycznych, poprzedzone pilotażem. - Uruchomienie platformy wymiany wiedzy „Czysty biznes” dla partnerów biznesowych.
	Motywowanie pracowników i partnerów biznesowych poprzez realizację celów związanych z ochroną klimatu	Dotkania edukacyjne skierowane do pracowników, franczyzobiorców i partnerów biznesowych.
Źródła energii	Obniżenie kosztów inwestycji w OZE i zwiększenie efektywności wytwarzania energii odnawialnej	- Zapewnienie dostępu do finansowania na korzystnych warunkach w perspektywie długoterminowej. - Studium wykonalności uzyskiwania opłacalnego i optymalnego pod względem technologicznym dostępu do OZE.
Produkty i usługi	Wzrost popytu na produkty mające niski lub zerowy ślad węglowy	Research w zakresie składników i produktów niskoemisyjnych oraz ewentualne zwiększanie skali ich stosowania lub wytwarzania.
Rynek	Zwiększenie lojalności klientów, dla których dbałość o środowisko jest istotna	- Znajomość potrzeb Klientów i skuteczna komunikacja w sprawach związanych z ochroną środowiska. - Realizacja strategii budowy wizerunku Grupy jako pracodawcy zaangażowanego w ochronę klimatu.
	Korzystny wizerunek Żabki jako pracodawcy zaangażowanego w ochronę klimatu	- Monitorowanie pozycji Grupy Żabka na tle podobnych organizacji. - Prowadzenie badań w zakresie składników i produktów niskoemisyjnych oraz ewentualne zwiększanie skali ich stosowania lub wytwarzania.
Odporność	Zwiększanie odporności łańcucha wartości dzięki realizacji inicjatyw	- Ogłaszanie oczekiwań w zakresie redukcji emisji gazów cieplarnianych na dorocznym spotkaniu z kontrahentami. - Indywidualne sesje planowania strategicznego z kluczowymi partnerami. - Uruchomienie platformy wymiany wiedzy „Czysty biznes” dla partnerów biznesowych.
Ocena szans według systemu ERM: ■ Mała ■ Średnia ■ Duża ■ Bardzo duża		

Figure 6. Infographic - climate risks and opportunities.

Source: Raport roczny Żabka Group, p. 83.

At the denotative level, the infographic catalogs four categories of climate risks (acute and chronic physical, transitional market and political-legal) and five categories of opportunities (resource efficiency, energy sources, products and services, markets, resilience), assessed on a four-point scale. Connotatively, however, the message extends far beyond neutral data presentation. The symmetrical distribution of risks and opportunities suggests balance and control over the situation. Warm warning colors (yellow, orange) on the threat side contrast with calm, professional blue tones on the opportunity side, visually communicating a transition from anxiety to mastery. The dominance of navy and light blue colors in the lower part of the table - symbols of stability, trust, and professionalism - optically suggests the prevalence of opportunities over threats.

The artifact operates with several significant cultural codes. First and foremost, it fits into the discourse of green capitalism, naturalizing the belief that the climate crisis can primarily constitute a business opportunity rather than a fundamental threat requiring systemic transformation. The myth of technological solutionism is omnipresent here - it suggests that appropriate risk management and innovation are sufficient to solve the problem. The ideology of control and quantification is also crucial here. The transformation of climate uncertainty into quantified risk on the ERM scale carries a reassuring message: the situation is measurable, and therefore manageable. This naturalizes human dominance over nature and reinforces belief in the possibility of maintaining the existing model of economic growth.

Paradigmatic choices are highly significant. Instead of actual actions, response plans are presented, which minimizes the impression of inaction. Instead of responsibility for caused climate changes, risks are discussed - which semantically shifts the company from the position of perpetrator to the position of victim of external circumstances. Most importantly: instead of moral obligations, business opportunities are discussed, which instrumentalizes ethics in favor of market logic. Syntagmatic relations reinforce these meanings. The left-right arrangement (risks-opportunities) creates a progressive narrative: from problem to solution, from threat to possibility. Placing the greatest risks at the end of the table makes them less noticeable during cursory reading. The dispersion of navy color on the right side optically suggests an abundance of opportunities.

In the context of the escalating climate crisis, which requires fundamental changes in business models and consumption patterns, the infographic serves an ideologically reassuring function. It communicates that radical transformation is not necessary - appropriate risk management and exploitation of market opportunities are sufficient. This is a classic example of corporate green mythology, where reporting compliance substitutes for actual action, and the narrative of economic growth driven by green transformation replaces the difficult debate about the necessity of limiting consumption or degrowth. The infographic naturalizes the conviction that capitalism not only can but must continue to develop - albeit in a "green" form.

Ultimately, the analyzed artifact constitutes a sophisticated corporate communication tool that, under the guise of transparency and responsibility, reinforces the status quo and postpones fundamental questions about systemic change in favor of technical-managerial solutions within the existing economic order.

4.3.4. Functional Profile

Functional analysis reveals 558 total instances—the highest functional multiplicity across cases. Informational functions overwhelmingly dominate with 229 instances (41.0%), led by logos (76), tables (64), and icons (55), establishing report's primary orientation as regulatory data disclosure document. Persuasive and emotional functions emerge as nearly equivalent secondary priorities with 108 and 102 instances respectively, both concentrated in logos (76 each) that function as triple-purpose anchors serving informational, persuasive, and emotional roles simultaneously. Photographs serve primarily emotional purposes (15 of 27), despite minimal presence. Comparative functions appear 55 times, dominated by tables (36). Interpretive functions contribute 41 instances, with tables (16) and illustrations (9) driving methodological explanation. Narrative functions appear minimally with only 23 instances. Tables function exclusively for informational and comparative purposes, maintaining strict objectivity. The complete absence of charts despite data intensity indicates preference for tabular organization over graphical visualization, reflecting regulatory compliance model balancing factual transparency, strategic advocacy, and emotional engagement while prioritizing verifiable data as credibility foundation.

4.4. Cross Case Analysis

All three sustainability reports - Lidl Polska, Biedronka, and Żabka - demonstrate striking convergence in their visual communication strategies despite significant structural differences. Most remarkably, all three systematically avoid conventional data visualization through charts (Lidl 0.35%, Biedronka 0.21%, Żabka 0%), suggesting deliberate preference for emotional and symbolic communication over quantitative transparency. All employ high visual density ranging from Lidl's 2.03 to Żabka's extraordinary 5.89 elements per page. Text-visual ratios reveal strategic choices: Lidl allocates 64% of space to visuals despite lowest element density, indicating larger comprehensive elements, Biedronka maintains balanced 47/53 distribution, while Żabka dedicates 59% to visual content through numerous discrete symbolic elements.

The ideological operations embedded within these reports reveal consistent patterns. Each presents business priorities as naturally aligned with social and environmental good while systematically shifting accountability from corporation to consumers, positioning them as primary agents of sustainability. Strategic omissions are universal: power structures remain invisible, negative impacts absent, foreign ownership obscured, and idealized representations replace actual conditions. All leverage external institutions for legitimization. Semiotic analysis reveals how these reports naturalize corporate ideologies: Lidl's materiality matrix suggests objectified ethics where business interest correlates with social good, Biedronka's anniversary

timeline constructs corporate paternalism through partnerships that position the foreign retailer as authentic Polish civic actor, Żabka's climate risk infographic reframes existential threats as business opportunities through balanced visual symmetry and color coding that suggests control and manageability, while Biedronka's diversity infographic celebrates statistics that potentially conceal non-compliance with disability employment mandates. Semiotic analysis of Lidl's African cocoa farmer photograph reveals how it perpetuates postcolonial narratives through aestheticized pre-modernity, constructing "fair trade" as solution while maintaining asymmetric economic relations.

Despite shared ideological operations, the three reports diverge fundamentally in structure and audience. Lidl's 141-page comprehensive document targets ESG analysts and informed stakeholders through systematic sustainability coverage. Biedronka's 131-page report addresses general Polish public through accessible tripartite structure. Żabka's compact 67-page document functions as technical compliance reference for regulators and financial stakeholders aligned with European Sustainability Reporting Standards.

The dominant visual strategies reveal distinct communication philosophies. Lidl employs photography-dominant authenticity strategy (31.36% photographs - highest across cases - depicting employees and stakeholders) combined with icons (22.65%), creating narrative-image reporting with sense of proportion that balances authentic representation with strategic symbolism. Biedronka pursues design-intensive branding strategy where decorative elements overwhelmingly dominate (46.48% - highest single category proportion), supplemented by photographs (21.96%) and icons (10.02%), creating communication based on aesthetics and emotions - engaging but less analytical. Żabka adopts efficiency and regulatory strategy through icons (27.09%), graphic elements (20.25%), and logos (19.24% - highest logo deployment), with minimal photography (6.84% - lowest) and maximum table use (16.20% - highest), creating functional, iconic visuality with high formalization.

Functional profiles reveal fundamentally distinct priorities. Lidl uniquely achieves emotional primacy (116 instances, 35.11%) with nearly equivalent informational secondary (115 instances, 33.82%) - only one instance difference representing perfect balance between accountability and affective connection. Biedronka demonstrates informational dominance (142 instances, 37.36%) with substantial emotional secondary (91 instances, 23.95%), combining factographic message with emotional CSR tone through educational and socially friendly communication. Żabka's overwhelming informational dominance (229 instances, 41.04% - highest absolute and proportional) with persuasive (108 instances, 19.35%) and emotional (102 instances) secondaries establishes orientation as regulatory disclosure document where emotions give way to transparency and fact-based persuasion.

The ideological positioning reveals distinct cultural strategies and corresponding "washing" practices. Lidl pursues global-local authenticity through supply chain narratives that naturalize Global South producers as traditional guardians whose pre-modern conditions justify their position in global value chains (greenwashing and fairwashing). Biedronka executes strategic

Polonization, naturalizing Portuguese ownership through patriotic partnerships while statistical presentations potentially conceal compliance failures (diversity-washing and “Poland-washing”). Żabka embraces technocratic managerialism, systematically reframing climate risks as market opportunities and presenting compliance as leadership (greenwashing and technowashing).

Ultimately, all three reports demonstrate corporate sustainability reporting as ideological apparatus where visual communication naturalizes corporate priorities as universal goods, minimal change as radical transformation, and management as ethics. The fundamental contradiction shared across cases: tools presented as objective assessment mechanisms actually function as instruments for legitimizing predetermined corporate priorities through language of standards and metrics. The reports differ in functional emphasis - Lidl's emotional-informational balance through photographic authenticity, Biedronka's accessible information wrapped in aesthetic sophistication, Żabka's regulatory compliance through formalized data presentation - yet all share commitment to sustainability credibility theater: elaborate performance of accountability without fundamental transformation of power structures or business models. Table 2 presents a comparison of the obtained test results.

Table 2.
Comparative summary of research results

Item	Biedronka	Lidl	Żabka
Total pages	131	141	67
Total visualizations	469	287	395
Visualizations/page	3.58	2.03	5.89
Text-visual ratio	47/53	36/64	41/59
Dominant type (Top 3)	Other graphic elements (46.48%), Photographs (21.96%), Icons/pictograms (10.02%)	Photographs (31.36%), Icons/pictograms (22.65%), Other graphic elements (16.38%)	Icons/pictograms (27.09%), Other graphic elements (20.25%), Logos (19.24%)
Second type	Tables, Infographics, Maps, Illustrations, Logos, Charts	Tables, Infographics, Illustrations, Logos, Charts, Maps	Tables, Photographs, Infographics, Maps, Illustrations, Charts
Primary function	informational 142 (37.36%)	emotional 116 (35.11%)	informational 229 (41.04%)
Secondary function	emotional 91 (23.95%)	informational 115 (33.82%)	persuasive 108 (19.35%)

Source: based on own results.

The comparative analysis reveals systematic ideological convergence - avoidance of quantitative visualization, alignment of business priorities with social good - yet fundamental divergence in visual strategies: Lidl's photography-dominant authenticity, Biedronka's design-intensive branding, and Żabka's icon-driven regulatory compliance. Corporate sustainability reporting ultimately operates as visual performance of accountability where professional aesthetics naturalize corporate worldviews while maintaining existing business models.

5. Discussion

This study reveals a striking paradox: as CSRD regulations intensify disclosure obligations, visual communication strategies systematically obscure the accountability these regulations seek to establish. The near-complete absence of charts across all three cases (Lidl 0.35%, Biedronka 0.21%, Żabka 0%) represents departure from transparency-oriented communication. While Beattie and Jones (2008) documented systematic manipulation within graph usage contemporary retail reporting reveals more sophisticated strategy: eliminating the analytical format entirely. This confirms Cho et al.'s (2015) thesis that organizations maintain organizational facades even under mandatory reporting regimes. Numerical data appear primarily in tables embedded within narrative contexts, lacking the comparative and temporal context that graphs provide.

The functional profiles reveal three distinct legitimacy strategies reflecting organizational contexts. Lidl's photography dominance (31.4%) and near-perfect emotional-informational balance constructs what Hrasky (2012) termed "legitimacy management through strategic use of visual imagery" - extensive stakeholder depiction creating visceral authenticity impression while minimizing analytical transparency. Biedronka's design-intensive approach (46.5% decorative elements) transforms the report into what Preston et al. (1996) identified as ceremonial communication, where aesthetic sophistication signals corporate modernity. Żabka's table-heavy strategy (16.2%) suggests that even compliance-oriented reporting resists visualization formats enabling comparison, aligning with Beattie and Jones's (2000) observation of "selectivity bias". These variations confirm Dumay et al.'s (2016) observation that standardization increases comprehensiveness but doesn't eliminate strategic differentiation, while supporting Hahn and Lülfs's (2014) argument that companies navigate legitimacy pressures through sophisticated disclosure strategies.

Semiotic analysis exposes the ideological work these strategies perform. Lidl's materiality matrix prioritizes business interests 4:1 over environmental impacts while employing what Davison (2015) termed visual rhetoric of objectivity - coordinate systems and quantitative scales masking corporate interest prioritization. The cocoa farmer photograph activates what Lyon and Montgomery (2015) identified as greenwashing through rhetoric without substance - aestheticized traditional imagery naturalizing asymmetric global value chains as equitable partnerships, precisely the pattern Hrasky (2012) documented where photographs served ceremonial and legitimizing functions. Biedronka's anniversary timeline constructs "Polishness" while obscuring Portuguese ownership, and the diversity infographic celebrates 1300 disabled employees potentially concealing non-compliance with statutory 6% mandate requiring 5000+ employees - exemplifying Mahoney et al.'s (2013) finding that sustainability reports often function as signaling mechanisms rather than genuine accountability tools. Żabka's climate risk infographic represents what Delmas and Burbano (2011) classified as

selective disclosure greenwashing, systematically reframing existential threats as manageable opportunities through what Cho et al. (2012) identified as strategic visual complexity.

Our central theoretical contribution identifies visual greenwashing not as isolated deceptive practices but as systematic architecture integrating five mechanisms: analytical visualization avoidance eliminating formats enabling evaluation, emotional substitution replacing analytical transparency with affective engagement, aesthetic legitimation deploying design sophistication as proxy for performance, semiotic naturalization normalizing corporate-favorable assumptions, and symbolic efficiency substituting verifiable disclosure with icon-heavy signaling. This extends foundational work establishing visual elements' ceremonial and legitimizing functions (Preston et al., 1996; Graves et al., 1996) by revealing how multiple visual elements integrate into coherent systems performing what Cho et al. (2015) termed "organized hypocrisy" - maintaining accountability appearance while protecting organizational interests. The near-zero chart usage extends Lyon and Montgomery's (2015) selective disclosure tactic from content to format selection, while intensive photography deployment (Lidl 31.4%) constructs authenticity theater through what Davison (2007, 2015) termed visual-verbal synergy - photographs anchor textual claims while obscuring structural power relations.

These mechanisms manifest distinctively in retail due to sector characteristics. Unlike extractive industries where environmental harms are geographically concentrated and measurable, retail's distributed accountability - labor practices across thousands of stores, global supply chains, diffuse waste - resists quantification and enables emotional visualization strategy. Visual elements perform legitimacy work distinctively through semiotic operations - connotation, cultural codes, ideological naturalization (Davison, 2013) - rather than explicit propositional claims subject to verification. This semiotic legitimacy work represents evolution in impression management: moving from textual claims (increasingly scrutinized) toward visual rhetoric operating through connotation and cultural association (Cho et al., 2010).

Our findings contribute to debates about ESG standardization (Dumay et al., 2016; Bebbington, Unerman, 2018) by revealing how mandatory frameworks interact with communication strategies. CSRD mandates content but not visualization approaches, creating regulatory gaps where companies maintain strategic control. All three retailers comply technically with CSRD/ESRS - they disclose mandated topics and numerical data - yet visualization choices systematically undermine transparency objectives, confirming fundamental limitation in content-focused regulation identified by Cho et al. (2015): mandating what companies report doesn't ensure how they communicate shapes stakeholder understanding toward accountability.

These findings challenge companies to recognize that sophisticated visual strategies, while serving short-term impression management (Cho et al., 2012), ultimately undermine stakeholder trust that sustainability reporting purportedly builds (Hahn, Lülfs, 2014). Companies genuinely committed to sustainability leadership should embrace analytical visualization as credibility foundation - chart avoidance represents missed opportunity to

demonstrate transparency, countering Beattie and Jones's (2008) finding that graph manipulation concentrates among poor performers. They should balance emotional and analytical elements strategically, ensuring charts constitute substantial proportion with emotional elements supporting rather than substituting transparency; rigorously apply double materiality frameworks avoiding corporate interest prioritization that subverts stakeholder accountability (Dumay et al., 2016); deploy semiotic awareness recognizing that visual elements communicate through connotation beyond literal content (Davison, 2015); and make omissions explicit rather than relying on format choices to obscure limitations, as strategic omissions become greenwashing when systematically excluding stakeholder-needed information (Lyon, Montgomery, 2015).

Study limitations qualify findings' scope. Three -case design enabled rich analysis but limits generalization; findings reflect Polish retail characteristics potentially not transferring to other contexts. Single-year analysis provides current snapshot but cannot reveal visualization evolution; reports analyzed reflect CSRD implementation process, potentially showing transitional practices. Qualitative semiotic analysis yields rich insights but introduces researcher subjectivity despite systematic procedures. Published reports examine official self-presentation rather than internal decision-making or stakeholder reception - the gap between intended impression management and actual sense-making remains empirically open. Future research should extend visualization analysis cross-sectorally, track longitudinal evolution across reporting cycles, employ experimental studies examining how visualization strategies affect stakeholder perceptions, correlate visualization characteristics with independent ESG performance assessments testing whether visual greenwashing concentrates among poor performers, and conduct stakeholder-focused studies examining actual report usage and interpretation - the critical empirical gap.

6. Conclusions

This study examined ESG visualization strategies employed by Lidl Polska, Biedronka, and Żabka through systematic analysis of their 2023-2024 sustainability reports, addressing critical gap: while research has concentrated on textual disclosure (Hahn, Kühnen, 2013; Dumay et al., 2016), visual communication elements have received limited systematic analysis despite occupying substantial report space and serving strategic functions (Preston et al., 1996; Davison, 2015). Most striking is fundamental convergence on visualization strategies privileging emotional engagement over analytical transparency despite organizational diversity - all three retailers demonstrate near complete chart avoidance (averaging 0.19%), representing evolution from the selective graphing and manipulation documented by Beattie and Jones (2008) and Jones (2011) to strategic format elimination. This suggests sector-level dynamics:

retail's distributed supply chain complexity creates reporting pressures favoring impression management over accountability, resulting in technical CSRD adherence through formats undermining transparency objectives.

The central theoretical contribution demonstrates that visual greenwashing operates not through isolated deceptive practices but as comprehensive strategic architecture integrating five mechanisms: analytical visualization avoidance, emotional substitution, aesthetic legitimation, semiotic naturalization, and symbolic efficiency. This extends foundational work establishing visual elements' ceremonial and legitimizing functions (Preston et al., 1996; Graves et al., 1996; Hrasky, 2012) by revealing how multiple visual elements integrate into coherent systems performing what Cho et al. (2015) termed “organized hypocrisy”. Semiotic analysis revealed these mechanisms' operation: materiality matrices presenting corporate priorities as objective measurement, photographs naturalizing inequalities as equitable partnerships (confirming Hrasky's 2012 findings), infographics reframing threats as opportunities, and statistical presentations potentially concealing non-compliance. These examples demonstrate visual rhetoric performing legitimacy work through connotation resistant to verification (Davison, 2007, 2015), representing evolution from textual claims toward visual communication exploiting what Delmas and Burbano (2011) identified as greenwashing tactics adapted to mandatory disclosure contexts.

While core architecture converges, manifestation reflects organizational characteristics - Lidl's photography-dominant authenticity strategy, Biedronka's design-intensive branding approach, and Żabka's regulatory-efficiency model demonstrate that standardized frameworks (CSRD) increase comprehensiveness but don't eliminate strategic differentiation (Dumay et al., 2016), confirming fundamental limitation: mandating what companies report doesn't ensure how they communicate aligns with accountability objectives (Cho et al., 2015). This research contributes to ongoing debates about sustainability reporting effectiveness, engaging the transparency versus legitimation tension (Hahn, Lülfs, 2014; Cho et al., 2015) by providing visual analysis evidence that contemporary reporting, despite expanding regulatory requirements, continues serving impression management more than stakeholder information needs. It addresses standardization versus contextualization debates (Dumay et al., 2016; Bebbington, Unerman, 2018), demonstrating how mandatory frameworks enable compliance without ensuring transparency, and advances the visual turn in accounting research by revealing visual rhetoric as primary mechanism through which companies navigate accountability pressures.

For companies, findings challenge assumptions that sophisticated visual communication builds genuine trust - systematic visual greenwashing deployment suggests industry normalization of practices ultimately undermining credibility as stakeholder capabilities intensify. Companies genuinely committed to sustainability should embrace analytical visualization as credibility foundation, balance emotional and analytical elements based on

stakeholder needs, ensure materiality assessment reflects stakeholder priorities, and make omissions explicit rather than obscuring through format choices.

The gap between regulatory objectives (transparent, comparable, decision-useful information) and documented practices (strategic formats minimizing transparency while maintaining accountability impression) suggests current reporting paradigms require reconsideration. Content mandates without format requirements create space for sophisticated greenwashing undermining policy objectives. Regulators should establish mandatory analytical visualization requirements that ensure quantitative data is presented in formats enabling comparison and evaluation (charts, graphs, trend analyses), proportionality standards that prevent overwhelming analytical content with decorative or emotional elements, and explicit prohibitions on misleading visual techniques such as presenting corporate priorities as objective assessments or using aesthetic sophistication to substitute for performance transparency. The convergent patterns identified - chart avoidance, emotional substitution, aesthetic legitimization, semiotic naturalization - likely represent systematic characteristics of corporate sustainability communication under mandatory disclosure rather than Polish-specific anomalies. Yet companies face genuine tensions: diverse stakeholder audiences, sustainability challenges involving quantifiable metrics and qualitative values, and reports that must inform and engage. The challenge lies not in eliminating visual communication but developing approaches genuinely balancing transparency with accessibility, accountability with engagement. Achieving this balance requires commitment from multiple actors: companies embracing transparency as competitive advantage, regulators developing requirements attending to format alongside content, civil society enhancing analytical capabilities and maintaining pressure, and researchers continuing to investigate how corporate communication practices either enable or impede the sustainability transformations that contemporary challenges urgently demand.

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THE EVOLUTION OF TOURIST PREFERENCES IN POLAND IN 2022-2025: A CASE STUDY OF OKUNINKA AT LAKE BIAŁE

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Purpose: The purpose of this paper is to analyze the evolution of tourist preferences in Poland between 2022 and 2025, using the case of Okuninka at Lake Białe. The research seeks to identify key trends such as the shortening of stays, the growing role of social media in decision-making, the demand for premium amenities, and demographic differences in leisure expectations.

Design/methodology/approach: The study is based on a mixed-methods design combining qualitative and quantitative techniques. The empirical data were collected through (1) content analysis of social media posts and comments, (2) in-depth interviews with accommodation providers, and (3) participant observation conducted on-site during the tourist seasons of 2022-2025. Triangulation of methods increased the robustness of findings. Statistical analyses (t-tests, χ^2 tests) were used to identify significant patterns, while thematic analysis provided deeper insights into motivations and perceptions.

Findings: The results reveal a clear shift from week-long vacations to short-term, weekend-oriented stays, often booked less than a week in advance. Premium amenities such as jacuzzis, saunas, and wellness zones have become decisive competitive factors. Tourist expectations are strongly differentiated by age and gender: younger visitors seek entertainment and social interaction, older groups prioritize peace and comfort, women emphasize aesthetics and amenities, while men focus on price–location balance. Observations highlight the contrast between families and younger tourists, as well as the popularity of cottages that enable private gatherings and barbecues. Rising perceptions of an unfavorable price-to-quality ratio indicate increasing consumer sensitivity to costs.

Research limitations/implications: The study is limited to one seasonal destination and to the period of 2022–2025, which may restrict generalizability. Data from social media capture public discourse but not necessarily private motivations. Future research could broaden the scope by including comparative analyses of other Polish tourist regions, longitudinal studies beyond 2025, and deeper exploration of the environmental and cultural impacts of short-term tourism.

Practical implications: The findings suggest that accommodation providers must adapt to a new consumption model by offering short-stay packages, investing in premium amenities, and adopting flexible pricing strategies. Effective use of social media for last-minute marketing becomes crucial. For regional policymakers, the results indicate a need to support

diversification of tourism products and year-round attractions to mitigate the risks of seasonality.

Social implications: The growing popularity of short, intensive leisure trips affects local communities by concentrating noise, traffic, and crowding in peak periods. Families staying close to the entertainment center often face conflicts between accessibility and the need for quiet. The rising number of tourists traveling with pets highlights new challenges for infrastructure and service design. Findings may inform community discussions on sustainable tourism, public space management, and coexistence of diverse tourist groups.

Originality/value: (The paper provides one of the first comprehensive analyses of post-pandemic tourist behavior in a Polish seasonal resort, combining social media analytics with interviews and field observations. It offers both theoretical insights into changing patterns of tourism consumption and practical recommendations for local businesses and policymakers.

Keywords: tourist preferences; short-term tourism; social media; Okuninka; Lake Białe.

Category of the paper: Research paper; Case study.

1. Introduction

Changes in tourist preferences represent one of the key challenges for the contemporary tourism economy. Dynamic social, economic, and technological processes significantly affect the way destinations are chosen, trips are planned, and expectations regarding stays are defined. Short-term trips, often organized spontaneously, are gaining increasing importance, while consumer decisions are more frequently based on information available in social media and reviews shared by other Internet users.

In Poland, this phenomenon is particularly evident in seasonal destinations that have long attracted visitors from both the region and beyond. Okuninka, located at Lake Białe, provides an example of a microregion where tourist traffic is concentrated mainly during the summer season. Along with the growing popularity of this location, visitors' expectations are also changing: in addition to basic accommodation services, there is a growing demand for higher standards and premium amenities, such as hot tubs, jacuzzis, or saunas.

The analysis of tourist preferences also reveals clear generational and gender-based differences in approaches to leisure. Younger tourists primarily seek entertainment, a dynamic lifestyle, and opportunities for social integration, whereas older groups attach greater importance to peace, quiet, and comfort. Women tend to emphasize the aesthetics of the place and additional amenities more often, while men are more focused on the price–quality ratio and convenient location.

Tourist decisions are increasingly shaped by economic factors, including inflation and rising living costs. Visitors expect high-quality services while simultaneously optimizing expenditures, which forces accommodation providers to flexibly adapt their offerings—both in terms of the length of stay (e.g., weekend packages) and the diversity of additional services.

The dynamic transformations in tourist behavior in Poland after 2020 give rise to new research challenges related to adapting traditional models of tourism consumption to socio-economic and technological realities. Phenomena such as the shortening of stays, the growing importance of last-minute bookings, the influence of social media on decision-making, and the rising demand for premium amenities indicate the emergence of a new paradigm of domestic tourism. The research problem of this study focuses on the question of how tourist preferences in Poland evolved between 2022 and 2025 using the example of Okuninka at Lake Białe, and what social, economic, and cultural factors determine these changes. This case study makes it possible to capture both the local specificity of the phenomenon and the broader processes of transformation in short-term tourism in Poland.

The aim of this article is to provide an in-depth analysis of changes in tourist preferences in the years 2022-2025, based on the case of Okuninka and Lake Białe. The empirical basis of the study consists of social media posts, interviews with accommodation providers, and field observations. The results make it possible not only to capture the specificity of local tendencies but also to indicate broader directions of change in domestic tourism.

2. Contemporary Changes in Tourist Preferences – A Literature Review

Changes in tourist preferences are the subject of intensive research in the international literature. Particular attention is paid to the growing popularity of short-term weekend trips, which in many regions are beginning to dominate over traditional, longer forms of leisure. An example is research conducted among tourists from Budapest visiting waterside destinations, where the predominance of short-term travel was clearly confirmed, resulting, among other things, from time and economic constraints, as well as studies carried out in Barcelona (Kádár, Gede, 2022; Suriñach et al., 2019). These findings correspond with trends observed in Poland, where recreational trips lasting only a few days, often organized spontaneously, are increasingly chosen.

A second important area of research is the role of social media in the process of selecting tourist destinations. As scientific analyses indicate, the impact of content published online is particularly strong in the case of new and unfamiliar places, whereas for well-established destinations this influence may be weaker (Johan Andersson, 2024; Tham et al., 2020; Wang, Yan, 2022). In the Polish context, this issue has also been studied, and researchers emphasize that although influencers and user-generated content are important sources of inspiration, they are not always treated as fully reliable decision-making tools (Zawadka, Liwińska, 2022). Similar conclusions are presented by Barbu and co-authors, who highlight the key role of social media marketing activities in shaping tourist choices, especially among young audiences (Barbu et al., 2024).

The importance of younger age groups in shaping new patterns of tourism consumption is also emphasized in Asian studies. Researchers point out that among young tourists in Malaysia, social media plays a crucial role in trip planning, selecting attractions, and ways of spending leisure time (Siti Yuliandi Ahmad, Nur Qasdina Asyura Pg Idris, 2024). These findings are consistent with observations concerning young Polish tourists, who prefer active forms of leisure and attach great importance to integration and entertainment aspects.

Another widely discussed element in the literature is the growing role of premium and luxury amenities in the accommodation sector. Available analyses show that the attractiveness of such services is strongly linked to tourists' emotional attachment to a destination brand ("Destination Brand Love"), which enhances their loyalty and willingness to incur higher expenditures (Morando, Platania, 2022; Swanson, 2017; Tang et al., 2023). Premium amenities thus become not only a factor of competitiveness but also a means of building lasting relationships between visitors and the place of stay.

The problem of seasonality in tourist traffic, which is one of the key challenges for summer holiday destinations, is also of great importance. According to scientific analyses, seasonality is a global phenomenon generating both opportunities and threats for local tourism economies (Duro, Turrión-Prats, 2019). Researchers point out that it is associated with difficulties in managing tourism infrastructure and providing stable employment, making local economies particularly sensitive to fluctuations in demand (Butler, 1998). The literature also emphasizes that seasonality affects not only economic but also social and environmental aspects—it leads to overuse of resources in peak season and their underutilization outside of it (Zvaigzne et al., 2022). Empirical analyses further indicate that in rural tourism, the intensity of seasonality is determined by both natural factors and the structure of the local service offer (Li, 2023). Other studies show that the development of cultural tourism can reduce seasonal fluctuations, attracting visitors even outside the summer period (Zhang et al., 2022). Practical recommendations, in turn, focus on the need to apply seasonality management tools, such as diversification of tourism products or organizing events outside the high season, which can stabilize demand and increase the attractiveness of a destination throughout the year (Hutsal, Stoliar, 2023). Researchers also point out that seasonality is rooted not only in economic and natural factors but also in cultural and institutional conditions, as confirmed by historical-anthropological analyses highlighting the role of demand distribution policies in shaping tourist flows (Rudihartmann, 1986). In destinations such as Okuninka, dependence on the summer season determines accommodation strategies and forces the adaptation of offers to a short period of intense demand, while at the same time creating a need to develop year-round products and implement measures to mitigate the effects of seasonality.

Polish studies on tourist preferences have examined leisure forms, accommodation choices, sources of information, and destination selection factors. Research indicates that price, user reviews, word-of-mouth marketing, and social media are increasingly decisive in shaping tourist behavior in Poland (Herbik, 2024). Other analyses show that tourists seek peace, contact

with nature, and cultural assets, with agritourism and “emotion tourism” (e.g. thematic villages) becoming more popular (Wojciechowska-Solis et al., 2022). In the context of sustainable development, studies highlight the extent to which Polish lodging facilities adopt low-emission practices and communicate these efforts to tourists (Rutecka et al., 2023). However, there are relatively few works covering the period 2022–2025 that focus on short-term weekend stays, premium amenities (e.g. jacuzzis, wellness zones), and demographic segmentation of preferences. The Okuninka case study therefore fills an important gap in the national tourism literature.

In summary, the literature clearly indicates three dominant trends in contemporary tourism: (1) the shortening of stays and the growing popularity of short-term travel, (2) the increasing role of social media in destination choice, and (3) the growing importance of premium amenities as a competitive differentiator. All these phenomena are reflected in the case of Okuninka at Lake Białe, which makes it an interesting case study for analyzing changes in tourist preferences in Poland.

3. Research Methodology

The research was conducted between 2022 and 2025 and employed three complementary data collection techniques: content analysis of social media, in-depth interviews, and participant observation. The application of methodological triangulation made it possible to obtain a comprehensive picture of the phenomenon, while the combination of qualitative and quantitative data increased the reliability of the findings.

The first technique was a content analysis of social media, focused on the Facebook group titled “Okuninka Jezioro Białe – noclegi (domki, pokoje, kwatery, pola namiotowe)”, which at the time of the last data collection had nearly 40,000 members. This group served as one of the main online forums for the exchange of information, opinions, and offers related to tourism in the Lake Białe region of Okuninka. The analysis covered both accommodation advertisements and tourists’ reactions in the form of questions, comments, and opinions, as well as interactions (likes, shares). A qualitative content analysis was applied, aimed at identifying dominant themes, communication patterns, and ways of presenting the tourism offer and participants’ experiences. The material was purposefully selected and included posts published during the peak tourist season (June–August), when activity was the highest, and outside the season (November–February), to capture differences in the intensity and character of discussions. In total, 1250 posts and 4860 comments were analyzed. The analysis was conducted in line with the principles of internet research ethics—data were collected from the public domain, without interfering with the content of the publications and without disclosing any personal information.

The second technique consisted of in-depth interviews conducted with 25 owners of accommodation facilities (holiday cottages, guest rooms, boarding houses). The conversations focused primarily on changes in customer behavior, length of stay, expectations regarding amenities, and booking methods.

The third element comprised participant observations, carried out on-site in Okuninka during the summer seasons of 2022–2025. They concerned tourist behavior and the use of tourism infrastructure, which made it possible to capture the dynamics of social interactions and recreational practices in the tourist space.

The collected empirical material was subjected to statistical analysis. The analysis covered the following quantitative data: length of stay, timing of reservations, and the importance of amenities in relation to tourists' demographic characteristics. Student's t-test for independent samples was applied to compare the average length of stay in 2022 and 2025, and χ^2 tests were used for qualitative variables (timing of reservations, expectations regarding amenities, demographic differences). The significance level was set at $\alpha = 0.05$.

The analysis of online data was based on publicly available content; all personal identifiers were removed, and quotations were presented in a generalized form. In interviews, respondents were assured anonymity and confidentiality, and participation was voluntary, in line with research ethics standards.

In light of the identified issues and research gaps, the following hypotheses were formulated:

- H1: Between 2022 and 2025, the average duration of tourist stays in Okuninka decreased, with short-term trips (2-3 days) becoming the dominant form.
- H2: Social media constitutes a key source of information influencing decisions regarding the choice of accommodation and timing of reservations.
- H3: The growing importance of premium amenities (jacuzzis, saunas, wellness zones) has become one of the main factors of competitiveness for accommodation facilities in the region.
- H4: Tourist preferences differ significantly depending on demographic characteristics such as age and gender.
- H5: Economic pressure related to inflation and rising living costs leads to an increasing number of tourists perceiving the price-to-quality ratio as unfavorable, which forces flexible pricing strategies.

The verification of the research hypotheses was carried out using both quantitative and qualitative analyses of the collected empirical material. Hypothesis H1 (shortening of stays) was verified using Student's t-test for independent samples, comparing the average length of stays in 2022 and 2025. In the case of hypotheses H2-H4, concerning the role of social media, the importance of premium amenities, and demographic differentiation of preferences, χ^2 tests of independence were applied, allowing for the determination of statistical significance of observed differences between qualitative variables (e.g., timing of reservations, choice of

amenities, preferences of women and men). An additional tool was the analysis of posts and comments in social media, which made it possible to capture not only the frequency of particular phenomena but also their contextual occurrence. Hypothesis H5, concerning the perception of the price-to-quality ratio, was verified using the χ^2 test and triangulated with the results of in-depth interviews, in which accommodation owners confirmed growing tourist expectations combined with cost pressure. The adoption of a significance level of $\alpha = 0.05$ enabled a reliable statistical evaluation of the data and limited the risk of type I errors.

4. Results of Own Research on Tourist Preferences in Okuninka

This chapter presents the results of empirical research conducted between 2022 and 2025, aimed at capturing changes in the preferences of tourists visiting Okuninka at Lake Białe. The analysis includes both quantitative and qualitative data obtained through field observations, in-depth interviews, and content analysis of posts published on social media. The results are presented in the form of tables and analytical commentary, which highlight the key trends regarding length of stay, booking strategies, the importance of premium amenities, demographic differences, and the perception of the price-to-quality ratio. This introduction serves as a starting point for a detailed presentation of the data, which illustrates the transformation processes of tourism consumption in the studied microregion.

4.1. Results of the Analysis of Posts and Comments on Facebook

Since 2022, the average length of tourist stays has been systematically decreasing. In 2022, week-long trips dominated, whereas in 2024 and 2025 shorter, weekend stays clearly prevailed. The year 2025 indicates a slight stabilization of this trend, which suggests the formation of a new model of tourism consumption (see Table 1).

Table 1.
Changes in Tourist Stay Duration (2022-2025)

Year	Average Stay (days)	Dominant Category	Statistical Test
2022	5.6 (SD = 1.9)	5-7 days	t(198) = 7.84; p < 0.001
2023	4.2 (SD = 1.4)	3-5 days	t(198) = 6.31; p < 0.001
2024	2.9 (SD = 1.1)	2-3 days	t(198) = 8.12; p < 0.001
2025	3.1 (SD = 1.2)	2-3 days	t(198) = 7.46; p < 0.001

Source: Authors' own elaboration based on Facebook group data analysis.

The average length of tourist stays decreased from more than five days in 2022 to around three days in 2024-2025. The data indicate a clear transformation of the leisure model, from traditional week-long holidays toward short-term weekend trips. This shift may be linked both to rising living costs and inflationary pressure, as well as to the lifestyle of younger generations, who prefer spontaneous, frequent, but shorter trips. The stabilization of the trend

in 2025 suggests that this model of tourism consumption is becoming the new norm, requiring accommodation providers to adjust their offers to short-term packages.

The data (see Table 2) show the growing spontaneity of tourist decisions—while in 2022 only 45% of bookings were made less than a week before arrival, by 2025 this share had already reached 64%. This trend is linked to the widespread availability of mobile booking applications and increased economic uncertainty, which discourages tourists from planning far in advance. In practice, this means the necessity of flexible capacity management, intensified marketing activities on social media, and the promotion of last-minute offers.

Table 2.
Timing of Reservations (2022-2025)

Year	>30 days (%)	7-30 days (%)	<7 days (%)	Test χ^2 (df = 6)
2022	25	30	45	$\chi^2 = 62.8$; $p < 0.001$
2023	21	26	53	
2024	18	21	61	
2025	16	20	64	

Source: Authors' own elaboration based on Facebook group data analysis.

The percentage of tourists interested in premium amenities increased more than threefold between 2022 and 2025 (see Table 3). The largest growth in demand concerned jacuzzis and wellness/spa zones, which are becoming one of the main competitive differentiators. This phenomenon indicates that even in seasonal destinations traditionally associated with simple leisure by the lake, tourists are increasingly expecting high standards and additional services that enhance comfort. Accommodation providers therefore need to incorporate investments in premium infrastructure into their strategies, which may raise the region's attractiveness in the longer term.

Table 3.
Importance of Premium Amenities (2022-2025)

Amenity	2022 (%)	2023 (%)	2024 (%)	2025 (%)	Test χ^2 (df = 9)
Jacuzzi	12	20	34	38	$\chi^2 = 54.2$; $p < 0.001$
Sauna	9	14	27	31	
Hot Tub	7	11	21	25	
Wellness/Spa	10	16	29	34	

Source: Authors' own elaboration based on Facebook group data analysis.

Tourist preferences vary significantly depending on age and gender (see Table 4). Young people (18–30 years old) prefer activity, social integration, and social life, while older groups (40+) seek peace and relaxation. Women more often emphasize the aesthetics of a place and the importance of amenities, whereas men place greater emphasis on price and location. Such differentiation suggests the need for market segmentation – accommodation facilities should prepare diversified service packages tailored to different target groups in order to compete more effectively in the market.

Table 4.*Demographic Differences in Tourist Preferences (2022-2025)*

Group	Dominant Preferences	Test χ^2
18-30 years	Parties, group activities	$\chi^2(4) = 33.4; p < 0.01$
31-39 years	Activity + comfort, price flexibility	
40+ years	Peace, comfort, relaxation	
Women	Aesthetics, amenities	$\chi^2(1) = 18.6; p < 0.05$
Men	Price, location	

Source: Authors' own elaboration based on Facebook group data analysis.

In the years 2022–2025, the share of tourists who believe that prices exceed the quality of services increases from 15% to 21% (see Table 5). At the same time, the number of people perceiving a balance between price and quality decreases. This trend shows that cost pressure, resulting among others from inflation and rising business operating costs, is reflected in customer perceptions. For accommodation owners, this means the need to implement flexible pricing strategies, offer promotions, and place greater emphasis on the added value of services (e.g., family packages, seasonal discounts, or bonuses for longer stays).

Table 5*Price-to-Quality Ratio in Tourist Perceptions (2022-2025)*

Year	Price > Quality (%)	Price $\approx$ Quality (%)	Price < Quality (%)	Test χ^2 (df = 6)
2022	15	60	25	$\chi^2 = 27.5; p < 0.001$
2023	16	55	29	
2024	18	52	30	
2025	21	49	30	

Source: Authors' own elaboration based on Facebook group data analysis.

4.2. Results of the In-Depth Interview Analysis

The thematic categories presented in Table 6, together with sample respondent quotations, illustrate the main problem areas identified in the course of the in-depth interview analysis. In the area of length of stay, respondents emphasized the predominance of short-term weekend trips, which are gradually replacing longer forms of leisure. They also pointed to the practical consequences of this phenomenon, including increased tourist turnover and the resulting higher organizational burdens for accommodation owners.

Table 6.*Thematic categories and sample statements of respondents*

Thematic category	Subcategory / Conclusion	Sample interview quotes*
Length of stay	Dominance of short weekend trips	"In the past people came for two weeks, now it's mostly Friday–Sunday" (R7)
	Higher guest turnover – more workload	"We have more cleaning and changeovers, but occupancy is almost full throughout summer" (R12)
Client expectations	Proximity to beach and gastronomy	"The most common questions are: how far is the lake and are there bars nearby" (R4)
	Growing importance of aesthetics and modern interiors	"Guests increasingly choose based on photos – it has to look nice and modern" (R16)

Cont. table 6.

Premium amenities	Popularity of hot tubs, jacuzzis, saunas	“When someone sees a jacuzzi in the listing, they book immediately, even if it’s more expensive” (R8)
	Economic challenges of maintenance	“The problem is the electricity and service costs – the season is short, and bills are high” (R20)
Booking strategies	Dominance of online and social media reservations	“95% of our bookings are online, mainly via Facebook and Booking” (R3)
	Growing importance of last-minute bookings	“Often they call on Thursday for the weekend – we must be ready” (R14)
	Decline in phone reservations	“Older people still prefer calling, but young people do everything in apps” (R22)

Note. Quotes from respondents’ interviews (*anonymized by assigning respondent numbers).

Source: Authors’ own elaboration based on Facebook group data analysis.

Within the category of customer expectations, two primary directions can be distinguished. On the one hand, the significance of basic locational attributes (e.g., proximity to a lake, access to dining facilities) remains evident; on the other, increasing importance is attached to aesthetic considerations and the quality of furnishings. This tendency appears particularly relevant in the context of the digitalization of booking processes, where visual materials play a decisive role in shaping consumer choices.

The analysis of premium amenities highlights their growing role in the competitive positioning of accommodation facilities. Features such as hot tubs, jacuzzis, and saunas constitute important market differentiators, facilitating the attraction of more demanding clientele and enabling higher price levels. At the same time, respondents emphasized the economic risks associated with maintaining such infrastructure, particularly in the context of short tourist seasons and rising operational costs.

With regard to booking strategies, digital channels clearly dominate, including online booking platforms and social media, which have assumed a central role in guest acquisition. Respondents also noted the increasing prevalence of last-minute reservations, which necessitates flexible management of availability and pricing policies. Only a minority of owners reported the continued, though diminishing, role of telephone bookings.

Overall, the collected statements provide clear evidence of an ongoing process of adaptation among accommodation providers to evolving consumer preferences and shifting market conditions. At the same time, the analyzed categories reveal a tension between the rising expectations of tourists and the economic as well as organizational constraints of operating in seasonally dependent destinations.

The data presented in Table 7 allow for capturing the frequency of occurrence of the identified thematic categories, thereby adding a quasi-quantitative dimension to the qualitative analysis. The highest proportion of responses relates to the area of length of stay, with as many as 84% of respondents confirming the predominance of short-term trips (2-3 nights). This result indicates a substantial shift in patterns of tourist consumption compared to previous years, when week-long or two-week stays were the prevailing standard in domestic tourism. This phenomenon finds confirmation in the existing literature, which underscores the growing significance of weekend tourism and spontaneous travel.

Table 7.*Frequency of occurrence of thematic categories among respondents (N = 25)*

Thematic category	Subcategory / Conclusion	Number of respondents	% of total sample
Length of stay	Dominance of short trips (2–3 nights)	21	84
	Growth of guest turnover and workload	15	60
Client expectations	Proximity to beach and gastronomy	19	76
	Aesthetics and modern interiors	14	56
	Safety and family-friendly facilities	10	40
Premium amenities	High interest in hot tubs/jacuzzis/saunas	18	72
	Economic challenges of maintenance	9	36
Booking strategies	Dominance of online reservations	20	80
	Growing role of last-minute bookings	17	68
	Decline of phone reservations	11	44

Note. Data based on structured interviews with 25 respondents. Quotes anonymized by assigning respondent numbers (R1-R25).

Source: Authors' own elaboration based on Facebook group data analysis.

With regard to customer expectations, the importance of location and access to dining facilities (76%) emerges particularly clearly, aligning with classical conceptualizations of factors determining the choice of holiday destinations. At the same time, more than half of respondents (56%) identified interior aesthetics and modern design as differentiating features of the offer, which may be interpreted as an expression of the aestheticization of tourist consumption. The relatively smaller proportion of references to issues of safety and family-oriented infrastructure (40%) suggests that these expectations are characteristic of selected market segments but do not determine choices on a general scale.

The analysis of the premium amenities category revealed that more than 70% of respondents recognize their growing competitive importance. At the same time, over one-third of respondents drew attention to the high maintenance costs of such infrastructure. These findings point to a structural tension between the pressure exerted by customers—seeking attractions that enhance comfort—and the financial and organizational constraints faced by entrepreneurs.

In the area of booking strategies, the dominant theme remains the digitalization of reservation processes. Eighty percent of respondents confirmed the predominance of online channels, while 68% highlighted the increasing significance of last-minute bookings. Both phenomena confirm the tendency toward shorter planning horizons and greater flexibility in consumer decision-making. The relatively low share of references to telephone bookings (44%) indicates their marginalization, although they remain important for certain clients with more traditional behavioral patterns.

In summary, the quantitative aggregation of qualitative data points to the dominance of three interrelated trends: the shortening of length of stay, the growing importance of aesthetics and premium amenities, and the digitalization of booking processes. These tendencies reflect profound transformations in the model of tourist consumption in seasonal destinations, including Okuninka.

4.3. Results of Observations

Observations conducted in Okuninka between 2022 and 2025 provided a multidimensional picture of tourist life at Lake Białe, revealing a pronounced differentiation in needs and leisure practices across age and social groups.

Daytime activities were dominated by recreational pursuits, with pedal boats and kayaks playing a particularly prominent role. These were most frequently chosen by young people and groups of friends, but also by families with children. Older tourists, by contrast, tended to prefer quieter forms of leisure, such as walking along the lakeshore, relaxing in cafés, or passive sunbathing. Increasing popularity was also observed in the cycling infrastructure developed around Okuninka, which enabled families with children to organize short excursions that diversified their lakefront stays.

After 10 p.m., the character of the locality underwent a marked transformation. The center of Okuninka became a space of nightlife, appropriated by youth and adults oriented toward entertainment. Bars, clubs, and food outlets in the central area played the dominant role, whereas venues located on the lakeshore but further from the center held less integrative significance. Social gatherings were often associated with alcohol consumption, generating noise and conflicts with families accompanied by children. Nevertheless, many families opted for accommodation near the center, which intensified their later dissatisfaction due to nighttime disturbances. Around midnight, tourist activity remained high both in venues and on the sidewalks leading to the center, which were congested with pedestrian traffic in both directions, including many children.

Regardless of visitor age or profile, summer cottages enjoyed widespread popularity, offering greater freedom than hotel rooms or compact guesthouse accommodations. They hosted social gatherings, barbecues, and music-filled parties, which constituted an important element of integration during stays. The choice of cottages facilitated flexibility from quiet family celebrations to loud youth gatherings underscoring the role of tourist preferences in shaping leisure forms.

Another significant aspect of observation concerned tourists traveling with pets, primarily dogs. This phenomenon necessitated adjustments in accommodation and recreational offerings, such as pet-friendly facilities or designated walking zones. Owners who introduced such solutions gained a noticeable competitive advantage.

Overall, the observations highlight the highly diverse needs of tourists visiting Okuninka ranging from peace and tranquility, through active family recreation, to intensive nightlife. This diversity represents both an asset and a challenge: while it allows the locality to attract a broad spectrum of visitors, it also generates spatial conflicts and requires carefully considered measures in managing tourist flows and tailoring the offer to heterogeneous audience segments. These observations are closely aligned with the studied tourist preferences (H1-H5), pointing, among others, to the shortening of stays, the significance of accommodation quality,

the growing role of additional amenities, and the differentiation of behaviors according to age and lifestyle.

4.4. Verification of Hypotheses

The process of verifying the research hypotheses was based on methodological triangulation, encompassing field observations, content analysis of social media, and the examination of secondary data. The application of diverse sources of information allowed for the construction of a highly reliable picture of the phenomena under study and minimized the risk of bias resulting from a one-sided research perspective.

In the case of H1 (shortening of tourist stays), convergent results were obtained both through observations (high tourist turnover, frequent changes in the occupancy of cottages and guesthouses) and through the analysis of social media content, where posts referring to weekend stays predominated. This confirmed the tendency toward short-term forms of leisure, consistent with the hypothesis.

Hypothesis H2 (the role of social media as an information source) received unequivocal confirmation. Content analysis on Facebook revealed that these platforms function as the primary channel for recommendations and the exchange of experiences concerning accommodation and attractions. Field observations supplemented these findings, indicating that booking decisions were frequently made on the basis of suggestions found online.

With regard to H3 (the growing importance of premium amenities), positive verification was provided by both qualitative data and observational findings. Mentions of jacuzzis, saunas, and wellness zones systematically appeared in social media content as decisive factors in the attractiveness of accommodation facilities. Observations further demonstrated that establishments offering such services achieved higher occupancy rates, thereby enhancing their competitive advantage.

Hypothesis H4 (differentiation of preferences by age and gender) was likewise confirmed. Observations indicated a clear diversification of activities (youth – water sports and nightlife; seniors – walking and tranquil leisure), while online content analysis revealed an additional gender-related dimension: women more frequently emphasized the need for family-oriented offers and child-friendly amenities, whereas men highlighted the importance of entertainment infrastructure.

Hypothesis H5 (economic pressure and assessment of the price–quality relationship) was also positively verified on the basis of triangulated sources. Secondary data analysis highlighted the growing impact of inflation on living costs, while social media posts repeatedly raised concerns about the high prices of accommodation and dining. Observations, in turn, pointed to a tendency to replace paid attractions with cheaper alternatives, confirming the subjective perception of a deteriorating price–quality ratio.

In summary, all research hypotheses were positively verified. The triangulation of methods enabled mutual reinforcement and complementarity of findings, as well as the capture of phenomena within their multidimensional context. The applied research approach confirmed the validity of combining observational methods, social media content analysis, and secondary data analysis in studies of contemporary forms of local tourism.

5. Discussion of Results

Economic changes, including inflation and the war, have contributed to the shortening of tourist stays and the optimization of expenditures, consistent with findings on domestic tourist preferences in Poland (Chomać-Pierzecka, Stasiak, 2024). In addition, the growing cost pressures and the perception that prices exceed quality highlight the need for flexible pricing approaches and the reinforcement of value-added elements in tourism offerings. The prevalence of short-term, weekend stays, increasingly observed in Okuninka, corresponds with trends promoted in small towns as efficient tourist destinations built upon cultural, natural, and social assets (Ostrowska-Tryzno, Pawlikowska-Piechotka, 2016). The spatial contrast between the lively center and quieter surrounding areas echoes observations of the “tourist field” in Amsterdam, where restaurants and services form complex segmentation patterns based on class and space (Terhorst, Erkuş-Öztürk, 2015). These short visits align with global trends of travel fragmentation and the rising importance of micro-trips. At the same time, as research on coastal tourism suggests, short-term travel often entails the intensification of activities and the compensation of reduced length of stay through the choice of attractions and services that enhance comfort (Carvache-Franco et al., 2025).

In Okuninka, a clear shift toward summer cottages has been observed, as they facilitate integration and social life (e.g., barbecues, gatherings), corresponding with trends noted in urban recreational spaces, where tourism increasingly prioritizes communal experiences. To some extent, Okuninka also aligns with patterns of rural tourism (Salvatore et al., 2018), yet with preferences more characteristic of urban tourism. The rising demand for premium amenities, such as jacuzzis and wellness zones, confirms the growing importance of luxury experiences as tools for building emotional bonds with destinations, the so-called Destination Brand Love (Morando, Platania, 2022).

The increasing interest in premium amenities such as jacuzzis and wellness areas resonates with global findings on the need for luxury experiences and the cultivation of emotional attachment to destinations (Destination Brand Love), which foster loyalty and greater willingness to incur higher costs (Morando, Platania, 2022; Tang et al., 2023). The results from Okuninka are consistent with trends in other regions, where premium amenities are perceived

not only as competitive differentiators but also as compensatory elements, intensifying experiences within shortened stays.

Demographic and spatial differentiation of preferences in Okuninka, youth oriented toward nightlife, families with children seeking tranquility, tourists traveling with dogs, and individuals preferring nature-based activities, finds ample confirmation in the literature. In practice, this translates into families choosing central locations despite the risk of noise, reflecting urban nightlife tourism patterns in which attractiveness concentrates around entertainment and communal spaces (Liu et al., 2023).

An increasingly important factor differentiating tourists in Okuninka is the growing number of visitors traveling with dogs. This phenomenon aligns with the expanding trend of pet-friendly tourism, highlighted in recent research that points to the role of pet-oriented amenities and infrastructure as determinants of destination choice and repeat visitation. The presence of dogs also alters recreational and spatial practices. In Okuninka, the needs of pet owners should be integrated into destination planning and infrastructure design to avoid conflicts between user groups. In Poland, a significant increase in dog ownership was observed during the COVID-19 restrictions, as a response to social isolation and reduced interpersonal contact (Dróżdż et al., 2021). This was accompanied by the rise of pet parenting among young adults, who increasingly opt for dog ownership in place of starting a family, framing care for animals as a lifestyle marker (Guo et al., 2021; Volsche, 2021).

Finally, economic changes, including inflation, uncertainty linked to the war in Ukraine, and rising living costs, exert a strong influence on the shortening of stays and the optimization of tourist expenditures, consistent with findings on national travel preferences in Poland (Zawadka et al., 2023). The growing share of tourists perceiving that prices exceed quality underscores the necessity of introducing flexible pricing strategies and enhancing value-added elements, such as service packages or last-minute promotions (Kashyap, Hong, 2025). In this context, market segmentation and precise targeting emerge as crucial tools for accommodation providers seeking to maintain competitiveness under dynamically changing market conditions.

Observed trends such as shorter stays, concentration of tourist flows in peak seasons, and growing demand for premium amenities (wellness zones, jacuzzis) pose risks of increasing environmental pressure on local ecosystems. Potential negative impacts include higher waste generation, increased per-unit water and energy consumption, shoreline degradation, noise, and stress on infrastructure (sewage, roads). Similar effects have been documented in Polish national parks, where heavy tourist traffic necessitates enhanced infrastructure management to avoid environmental degradation and landscape pressure (Adach et al., 2022). Although some facilities implement pro-environmental measures such as communicating low-emission initiatives (Rutecka et al., 2023), these are often insufficient given the growing scale of short-term tourism. The development of such tourism therefore requires stronger environmental safeguards, seasonal regulations, systematic monitoring of ecological effects, and the promotion of sustainable practices among both tourists and service providers.

6. Conclusions

Between 2022 and 2025, tourism in Okuninka and the White Lake area consolidated into a model of short, spontaneously organized weekend trips, with most reservations made less than one week prior to arrival. The shortening of stays has been accompanied by the rising importance of premium amenities, which compensate for limited leisure time and serve as a key competitive differentiator. Quantitative data confirm marked demographic differences in preferences: younger tourists seek entertainment and activity, older visitors prioritize peace and comfort, women emphasize aesthetics and additional services, while men focus on the price–location ratio. Simultaneously, a growing share of tourists perceive that prices exceed quality, and increasing cost pressures compel accommodation providers to implement flexible pricing strategies, invest in value-added services, and improve customer targeting.

Content analysis of social media has demonstrated the dominant role of visual aspects in shaping tourist decision-making. The aesthetics of facilities and surroundings, along with opportunities to share appealing content online, increasingly determine the choice of accommodation. Posts highlighting premium amenities, wellness infrastructure, and cultural or entertainment events generated the highest engagement, underscoring the growing significance of promotion based on visual narratives and authentic tourist experiences.

In-depth interviews confirmed tourists' expectations for high levels of comfort, even during short stays. Respondents emphasized the growing importance of service quality, while simultaneously expressing concerns that prices often outweigh value. Field observations revealed spatial segmentation of recreational areas, with younger groups concentrating around entertainment zones and the beach, while older visitors preferred quieter locations. Accommodation providers are increasingly aware of the need to modernize and differentiate their offerings through design and additional services.

The study is subject to certain limitations, including its focus on a single locality, reliance on publicly available social media content, and the qualitative nature of interviews, which provide in-depth but not fully representative insights.

Future research directions include comparative analyses across different tourist centers in Poland, studies on the potential to extend the tourist season, and further investigations into the role of social media and influencer marketing in shaping tourist decision-making.

Theoretical implications concern the development of tourism theory related to short-term stays and the aestheticization of tourist consumption, as well as the integration of social media analysis into consumer behavior research. The Okuninka case contributes to ongoing debates on managing seasonality and competitive strategies in micro-regional tourism contexts.

Practical implications emphasize the need to tailor offerings to short stays and last-minute bookings, invest in premium amenities, and strengthen visual promotion in social media. Equally important are the implementation of flexible pricing strategies and the development of year-round offerings supported by cultural events and wellness infrastructure, which may mitigate the effects of seasonality and enhance regional competitiveness.

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INNOVATIVE ECONOMY AND KNOWLEDGE MANAGEMENT AS A SOURCE OF COMPETITIVE ADVANTAGE: AN ECONOMIC AND INSTITUTIONAL APPROACH

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Purpose: The aim of this article is to analyse the role of knowledge management as a key mechanism for building competitive advantage for enterprises in a data-driven economy. The study adopts an economic-institutional perspective, according to which knowledge is both a strategic resource and an element of the system of regulations, incentives and institutions that influence the effectiveness of economic entities.

Design/methodology/approach: The article is conceptual in nature and is based on an analysis of literature in the fields of knowledge management, institutional economics, resource-based view, transaction cost theory and data economics. A research framework was applied based on a comparison of knowledge management mechanisms with institutional conditions and an assessment of their impact on value creation and competitive advantage of enterprises.

Findings: The consistency of regulations related to data, intellectual property and information security, the quality of data infrastructure and institutional support for innovation have a significant impact on the effectiveness of knowledge management systems and business performance. In a data-driven economy, the ability to convert data into knowledge, the quality of decision-making processes, and the integration of knowledge into the organisational system are of key importance.

Research limitations/implications: Due to the conceptual nature of the study, further empirical research is needed, including comparative sector analyses and quantitative studies.

Practical implications: The results indicate the need to adapt knowledge management systems to regulatory and infrastructure requirements. The article formulates recommendations for enterprises and public institutions supporting the information economy.

Social implications: In social terms, the study highlights the importance of ethical data and knowledge management as a factor that strengthens public trust and promotes sustainable development.

Originality/value: The work brings a new perspective by integrating knowledge management with institutional economics, highlighting the role of data and regulation as co-creators of competitive advantage architecture in the digital economy.

Keywords: knowledge management, data-driven economy, innovation, competitive advantage.
Category of the paper: Literature review.

1. Introduction

Knowledge management in enterprises operating in a data-driven economy is becoming one of the key factors shaping contemporary mechanisms of competitive advantage. The dynamic development of information technologies, the increasing digitisation of economic processes and the growing complexity of the institutional environment mean that knowledge – both explicit and tacit – is transforming into a strategic organisational resource that determines the ability of enterprises to adapt and grow (Kłak, 2024). The literature on the subject increasingly emphasises that organisational competencies in the acquisition, processing and use of knowledge determine the sustainability of competitive advantages, especially in an economy where data is becoming the basic category of value creation.

The improvement of knowledge management systems is part of a broader phenomenon of the evolution of contemporary management concepts, which aim to achieve ever greater synchronisation of internal organisational processes with the realities of the economic environment (Banaś, 2024). Appropriately tailoring organisational solutions to the requirements of a data-driven economy promotes both increased innovation and improved economic performance of enterprises (Serdyński, 2024). Both the conceptual foundations of knowledge management and the institutional framework for its functioning are universal in nature, which means that they can be implemented in enterprises with diverse business profiles (Ulhaq et al., 2024).

The aim of this article is to analyse knowledge management processes in relation to the conditions of a data-driven economy and to identify the relationships between information processing mechanisms, institutional structure and the ability of enterprises to achieve competitive advantages. The study is conceptual in nature and its structure is based on linking key elements of knowledge management with institutional conditions that shape the possibility of their use in economic practice. The result of the work is a set of conclusions and recommendations on how to strengthen knowledge management processes in enterprises whose functioning depends on the quality of data processing systems and their conversion into organisational knowledge.

The analytical framework used in the article allows for a clear presentation of the role of knowledge management processes in increasing decision-making efficiency, improving coordination of activities and strengthening the innovative potential of enterprises. This study is based on a broad review of the literature covering both the theoretical aspects of knowledge management and the economic concepts of institutions, intellectual property and data economics.

Identifying similarities and interrelationships between the economic function of knowledge and the institutional conditions for its use makes it possible to identify activities that can support enterprises in generating sustainable competitive advantages. Of particular importance here is the ability of enterprises to convert data into useful knowledge and to integrate information processes with the economic and strategic objectives of the entity.

2. Literature review

2.1. Theoretical foundations of knowledge management and its importance for competitive advantage

The concept of knowledge management is one of the key issues in contemporary management sciences and enterprise resource economics. The global literature emphasises that knowledge, both explicit and tacit, is a strategic resource that is highly difficult to imitate and determines the sustainability of competitive advantages (Oranga, 2023). Knowledge also serves as a factor that organises innovation processes, guides strategic decisions and enables the enterprise to adapt to technological and market changes.

In terms of resource theory (Battisti et al., 2022), a company's competitiveness is determined by resources with VRIN characteristics: valuable, rare, difficult to imitate and difficult to replace (Singh, 2022). Knowledge, especially organisational knowledge and team competencies, meets these criteria in a particularly clear way, becoming the basis for a lasting advantage over competitors.

The concept of organisational learning also makes a significant contribution to the development of the concept of knowledge as a resource. It should be emphasised that companies that build advantages in a volatile environment are characterised by their ability to learn systematically, which strengthens their adaptability (Mauludina et al., 2025). The need to combine operational learning with double-loop learning, which modifies the very rules of an organisation's functioning, is also important (Auqui-Caceres et al., 2023).

The literature on knowledge management also mentions the concept of epistemic diffusion, according to which an effective organisation should create structures and processes that enable the transfer of knowledge between individuals, teams and management levels (James, 2024). The effectiveness of diffusion increases within cultural cohesion and weakens in conditions of strong structural barriers.

From an economic perspective, knowledge is treated as intangible capital with increasing marginal productivity. The endogenous growth theory (Akcigit, 2021) argues that knowledge accumulation is self-reinforcing, leading to dynamic economies of scale, which makes knowledge management processes crucial for the long-term growth potential of enterprises.

The literature also emphasises that knowledge is the foundation of a data-driven economy, in which information is transformed into economic value through complex analytical, algorithmic and decision-making processes (Al-Okaily et al., 2023). The ability of enterprises to transform data into decision-making knowledge is now seen as a key determinant of market efficiency and innovation.

2.2. Institutional and regulatory conditions for knowledge management in a data-driven economy

An important trend in the literature is the analysis of the role of institutions, both formal and informal, in shaping knowledge management mechanisms. Institutional economics (Frolov, 2023) emphasises that institutions set the framework within which companies can accumulate, protect and use knowledge. These include regulations on intellectual property, personal data, information security, data openness, interoperability and cybersecurity standards.

The literature indicates that effective knowledge management depends on a balance between information openness and the protection of knowledge resources (Ali et al., 2023). Overly restrictive systems limit the possibilities for knowledge diffusion and cooperation, while overly open systems increase the risk of losing strategic organisational resources.

Work in the field of institutional governance theory also makes a significant contribution to the analysis of the relationship between institutions and knowledge. The authors argue that inclusive institutions promote the development of intellectual capital, innovation and entrepreneurship, while exclusive institutions limit access to knowledge and inhibit competition (Ząbkowicz, 2022).

In a data-driven economy, the regulatory framework for data circulation is of particular importance. Work in the field of data economics emphasises (Funk, 2023) that regulations concerning data quality, accessibility, standardisation and sharing affect the effectiveness of predictive analytics, the quality of algorithmic models and the possibilities for digital organisational learning.

The literature also highlights the growing importance of research on information infrastructure (Heinzl et al., 2024), which consists of digital platforms, database management systems, cloud technologies, and business analytics support systems. The authors point out that this infrastructure is a prerequisite for the effective operationalisation of knowledge management, especially in a data-intensive environment (Nauendorf, 2023).

2.3. Knowledge as an element of decision-making process architecture in enterprises

The literature on the subject (Heilig et al., 2023) emphasises that knowledge plays a fundamental role in decision-making processes, determining the quality and accuracy of strategic, tactical and operational choices. Digitalisation and the growing use of data are making corporate decision-making systems increasingly complex, and their effectiveness depends on the organisation's ability to convert information into knowledge that can be used in management

practice. The authors (Muntwiler et al., 2023) point out that limited rationality in decision-making is compensated for by mechanisms that support the acquisition and processing of knowledge, which minimises uncertainty and allows for better prediction of the effects of actions.

Contemporary research trends emphasise that knowledge is an essential condition for the efficient functioning of analytical systems, including predictive mechanisms and algorithmic models (Rosati et al., 2023). An organisation's ability to synthesise knowledge resources from both internal information archives and external market sources enables the creation of structural decision-making advantages that translate into competitive differentiation. Research in the field of data-driven decision-making also indicates that the value of managerial decisions increases with greater transparency and accessibility of data, which reinforces the role of information infrastructure as the basis for the integration of knowledge resources within an enterprise (Munagandla et al., 2024).

A significant part of the literature (Martínez et al., 2023) is devoted to the integration of decision-making processes with knowledge management systems, pointing out that organisations that are able to combine expert knowledge with the results of data analysis created by digital systems gain an advantage. The combination of these two components leads to the emergence of so-called hybrid decision-making processes, which are characterised by a higher level of consistency and less susceptibility to errors resulting from intuitive decision-making (Ala et al., 2023).

The literature also emphasises the role of organisational culture in shaping knowledge-based decision-making processes. Organisations with a culture that encourages experimentation, employee autonomy and openness to information show a greater ability to use data effectively in decision-making. It is pointed out that organisational culture is an intermediary between access to data and the ability to transform it into knowledge that is useful in management processes (Müller, 2022).

2.4. Knowledge management in the context of a data-driven economy: an overview of research trends and concepts

Research on knowledge management in a data-driven economy covers many theoretical trends, from the economics of innovation, through information systems theory, to institutional analyses of data as a strategic resource. One of the most important areas of research is the problem of transforming data into organisational knowledge, which is referred to in the literature as data-to-knowledge conversion. The authors emphasise that the effectiveness of this transformation depends on the quality of the data, the degree of its structuring, and the organisation's ability to create knowledge ontologies that allow for its systematic use (Ioakeimidou et al., 2025).

Economic literature is paying increasing attention to the relationship between data structure and competitive advantage, pointing out that high-quality, frequently updated data is the basis for building predictive models and machine learning processes that strengthen business innovation (Niedermeier, 2025). Great emphasis is placed on the importance of big data analytics, machine learning and artificial intelligence technologies as tools for increasing knowledge productivity and achieving a higher level of information integration (Rane et al., 2024).

An important area of research also concerns the role of institutions regulating data circulation. The literature analyses the impact of regulations on data protection, system interoperability and information security standards on the ability of enterprises to use data in knowledge management processes (Hovav, 2023). It is pointed out that regulatory frameworks create both constraints and opportunities that shape companies' information strategies. Properly designed institutions promote data exchange, reduce information asymmetry and improve coordination in network economies (Marhad et al., 2024).

The literature on the data-driven economy also emphasises the importance of digital infrastructure and platform ecosystems that enable the creation of dynamic and distributed knowledge networks (Nicotra et al., 2024). The authors point out that effective knowledge management requires the integration of analytical systems, Big Data platforms, cloud tools, and structures that enable knowledge sharing between organisations. The development of data ecosystems leads to the emergence of new forms of cooperation and co-opetition, which intensify learning and innovation processes in an inter-organisational context (Sultana et al., 2024).

2.5. Barriers and challenges in knowledge management in a data-driven economy

The literature emphasises that despite the growing importance of data as a strategic resource for enterprises, knowledge management processes face numerous technological, organisational, institutional and cultural barriers (Shadmanfar et al., 2024). The most frequently cited challenges include problems related to data quality, fragmentation and restrictions on access to information, which significantly hinder the process of converting data into organisational knowledge. Researchers also point to the risk of information overload, leading to a decline in the effectiveness of decision-making processes and difficulties in identifying information that is key to strategic objectives (Matthies, 2021).

Competence issues remain an important challenge. The literature emphasises that effective use of data requires a high level of analytical competence, the ability to interpret model results and the ability to implement them in management practice (Bakalis et al., 2024). The lack of specialised skills significantly weakens the effectiveness of knowledge management systems, as confirmed by research on the so-called digital skills gap (Hoe, 2025).

Infrastructural limitations are also a significant barrier, including the inefficiency of IT systems, the lack of interoperability between platforms, and difficulties in integrating data from various sources, both internal and external. Research indicates that companies with dispersed information resources encounter greater difficulties in building consistent knowledge management processes, which leads to increased coordination costs and the risk of analytical errors (Jarrahi et al., 2023).

The literature also emphasises the importance of regulatory barriers. Data protection standards, compliance requirements, restrictions on cross-border information flows and intellectual property regulations can both support and hinder an organisation's ability to manage knowledge effectively. Sometimes, overly stringent institutional frameworks limit the innovative potential of enterprises, hindering the creation of data ecosystems or inter-organisational knowledge sharing (Geissdoerfer et al., 2023).

From a cultural perspective, the lack of organisational trust and the insufficient willingness of employees to share knowledge remain a problem. Researchers emphasise that a culture of information reluctance leads to the creation of so-called knowledge silos, which disrupt the processes of knowledge diffusion and hinder the creation of shared competence resources (Offergelt et al., 2024). These barriers become particularly evident in organisations that have not developed formal knowledge circulation mechanisms and structures that support cooperation and information integration.

2.6. Directions for the development of research on knowledge and data

The scientific literature shows a dynamic development of new research trends in knowledge management in a data-driven economy (Pisoni et al., 2024). One of the most important areas of research is the analysis of the role of artificial intelligence, machine learning and predictive algorithms in the processes of creating and using organisational knowledge. The authors point out that these technologies not only enable the automation of decision-making processes, but also the creation of knowledge previously unavailable to companies, which redefines the boundaries of their competitive advantages (Mezina et al., 2024).

Another area of intensive research is the conceptualisation of data as a new category of productive capital. Economic literature proposes treating data as a separate type of resource, whose value increases as it is processed and integrated with other components of intangible capital (Medeiros et al., 2022). This research includes both modelling the economic value of information and analysing the dynamics of organisational learning in conditions of intensive data use (Barth et al., 2023).

Another important research trend concerns the processes of knowledge co-creation within data ecosystems (Bag et al., 2021). The development of digital platforms and information exchange networks fosters the creation of shared learning spaces where knowledge is created and developed by multiple interconnected organisations. The literature emphasises that contemporary competitive advantages increasingly result not only from internal resources,

but also from access to knowledge that is dispersed and created within networked environments (Hoppenstedt et al., 2025).

Institutional research also shows a growing interest in the role of the state in shaping data infrastructure, interoperability standards and policies supporting information innovation (Hodapp et al., 2022). It is pointed out that regulatory actions can increase data availability, enhance market transparency and create conditions conducive to the development of institutions supporting knowledge management (Gujar, 2025).

The literature also highlights a clear need to develop research on the ethical and social consequences of data use, particularly in the context of increasing automation of cognitive processes (Akinrinola et al., 2024). The issues of algorithmic accountability, model transparency and data ethics constitute a new, rapidly developing area of study that is shaping the future directions of knowledge management in organisations.

3. Methods

The methodology used in this study is based on a conceptual approach that aims to integrate theoretical findings in the field of knowledge management with the economic and institutional perspective specific to the data-driven economy. The article is not empirical in nature; its structure has been designed to enable a systematic analysis of the relationships between knowledge management processes, the role of institutions, and the mechanisms for building competitive advantages for enterprises.

3.1. Methodological objective and course of the study

The main methodological objective is to identify the key elements that constitute the advantages of enterprises in conditions of intensive data use. The article focuses on creating a synthetic theoretical framework that allows for the analysis of the processes of converting data into knowledge, the organisational mechanisms of its diffusion, and the institutional conditions regulating these processes.

3.2. Research approach

The conceptual and analytical approach used comprises three main stages:

- theoretical analysis,
- interdisciplinary synthesis, and
- conceptual modelling.

This approach necessitates the organisation of key analytical categories, as presented in Table 1, which defines the basic types of knowledge used in the study and their significance for management processes.

Table 1.*Categories of knowledge relevant to methodological analysis*

Knowledge category	Characteristics	Significance for analysis
Explicit knowledge	Structured, easy to document and transmit.	Enables the identification of formal processes.
Tacit knowledge	Based on the experience of individuals, difficult to formalise.	Crucial for interpreting decision-making mechanisms.
Procedural knowledge	Relates to methods of performing activities and organisational routines.	Important for mapping data processing processes.

Source: own study.

Taking into account the three above categories of knowledge provides the basis for building a coherent analytical structure that allows us to examine how companies create value based on data and institutional rules for its use.

3.3. Data sources and analytical procedures

The article is based on an analysis of secondary sources, selected for their theoretical and interpretative significance. Analytical procedures include:

- critical analysis of the literature,
- comparison of theoretical approaches,
- reconstruction of key conceptual categories,
- modelling of relationships between knowledge, institutions and competitive advantage.

The analysis revealed that knowledge management processes are subject to various constraints that determine their usefulness in economic practice. These barriers are summarised in Table 2.

Table 2.*Barriers relevant to knowledge management analysis methods*

Type of barrier	Characteristics
Technological	Low data quality, lack of system interoperability, infrastructure limitations.
Organisational	Siloed structures, lack of formal knowledge circulation processes.
Cultural	Reluctance to share knowledge, low level of organisational trust.
Regulatory	Restrictions resulting from legal norms concerning data and its protection.

Source: own study.

3.4. Justification for the selection of methods and model design

The choice of conceptual methods stems from the need to analyse complex, intangible and difficult-to-measure phenomena. Knowledge management mechanisms that integrate data, organisational processes and institutional frameworks of enterprise operation play a key role here. The most important of these are listed in Table 3.

Table 3.*Knowledge management mechanisms included in the conceptual model*

Mechanism	Description	Significance for the model
Conversion of data into knowledge	Transforming data into information useful for decision-making.	Indicates sources of information advantage.
Knowledge diffusion	Transferring knowledge between individuals and teams.	Determines the effectiveness of knowledge circulation.
Knowledge retention	Retaining key knowledge resources within the organisation.	Reduces the risk of losing competencies.
Knowledge integration	Combining knowledge from multiple sources and systems.	It is a prerequisite for process synergy.

Source: own study.

This structured methodology allows for a consistent link between the theoretical foundations and the interpretative model presented later in this study, ensuring clarity of the analysis criteria and transparency of the assumptions made.

4. Results and Discussion

The conceptual model developed in this article presents the relationships between the institutional conditions for the functioning of enterprises, knowledge management processes and data resources, which together determine an organisation's ability to achieve competitive advantage in a data-driven economy. The model's structure is based on theoretical analysis and organises key areas of influence, enabling the identification of cause-and-effect elements.

4.1. Model assumptions

The conceptual model is based on a set of assumptions that reflect the specific nature of how enterprises operate in a data-driven economy and their dependence on institutions, information processes and knowledge resources. Firstly, it was assumed that institutions, both in formal terms, including legal regulations, public policies, technical standards and information security standards, and in informal terms, including practices, customs and cultural patterns of behaviour, set the framework within which enterprises acquire, process and use data. These institutions shape not only the scope of available information resources, but also the acceptable methods of processing them, the level of system interoperability and the quality of infrastructure, which directly affects the effectiveness of knowledge management.

The second key assumption of the model is the role of knowledge management processes as a central mechanism for activating the potential of data. It is assumed that a company's ability to convert data into organisational knowledge, its diffusion between subsystems of the organisational structure, retention in key competence areas and integration at the operational and strategic levels is the foundation of an organisation's adaptive capacity. Knowledge management processes determine not only how information is transformed into a resource of

decision-making importance, but also the speed of the company's response to changes in the competitive environment and the effectiveness of innovation development.

The third assumption relates to data resources, which in a digital economy are the basis for creating economic value. These resources vary in terms of quality, availability, timeliness and degree of structuring, which affects their informational usefulness. The model assumes that high-quality and accessible data resources can strengthen organisational processes, provided that there are mechanisms capable of interpreting them properly. Data is therefore not treated as an autonomous resource, but as a component of an information system whose value is only revealed in knowledge management processes.

These assumptions lead to the conclusion that a company's competitive advantage results from the synergistic interaction of institutions, knowledge processes and data resources. An organisation achieves lasting market benefits only when it has access to stable and favourable regulations, is able to generate and maintain knowledge of high decision-making value, and uses data resources in a systematic and purposeful manner. This approach to the problem allows us to view competitive advantage not as a one-dimensional effect, but as a dynamic configuration of structural, procedural and informational factors, the effectiveness of which depends on the coherence of the entire system (Table 3).

Table 4.

Assumptions of the conceptual model and their analytical implications

Model assumption	Assumption content	Implications for analysis
Institutional conditions	Formal and informal institutions shape the conditions for data acquisition, processing and distribution.	Defining the boundaries of an organisation's activities and the level of accessibility of information resources.
Knowledge management processes	The organisation processes data into knowledge through conversion, diffusion, retention and integration.	The ability to assess the effectiveness of knowledge mechanisms and their impact on decisions.
Quality of data resources	Data varies in quality, availability and timeliness, which affects its usefulness.	The need to identify factors that increase the informational value of data.
Synergistic nature of advantage	Competitive advantage results from the combination of institutions, knowledge processes and data resources.	Approach to competitive advantage as the effect of a multidimensional system.

Source: own study.

The table organises the key dimensions of the model and shows that each of the assumptions contributes a separate but complementary element to the analysis of competitive advantage. Institutions define the framework for action, knowledge management processes transform data into a strategic resource, and data quality determines the value of potential information benefits. Only their synergistic interaction creates a coherent system in which a company can achieve sustainable competitive advantages. This structured framework enables the precise use of the model in the further part of the study.

4.2. Logic and structure of the model

The logic of the conceptual model is based on the assumption that the competitive advantage of companies operating in a data-driven economy is not the result of a single isolated factor, but stems from a multi-level system of relationships between institutions, knowledge management processes and data resources. The model's design has been shaped in such a way as to capture the complex relationships and feedback mechanisms between these areas, creating a systemic rather than a linear structure. Thus, the model is not merely a cause-and-effect illustration, but reflects a multidimensional system that drives the process of competitive advantage creation.

The first element of the model's logic is the assumption that institutions constitute a superordinate layer that determines the scope and possibilities of using information resources in enterprises. Institutions, in a sense that includes both regulations and social norms, organisational practices and data infrastructure, create a context within which enterprises can accumulate, process and exchange knowledge. It is institutions that set the acceptable limits for data use, define the level of data availability and shape incentives for investment in the development of information systems. The model therefore assumes that institutions act as a meta-control mechanism that determines the effectiveness of knowledge-related operations at the organisational level.

The second logical component of the model's structure is the recognition that knowledge management processes constitute an operational layer in which a company's ability to give economic utility to information resources is revealed. The processes of knowledge conversion, diffusion, retention and integration are placed at the centre of the model, as it is these processes that transform raw, often unstructured data of varying quality into a resource with decision-making and strategic properties. From the perspective of the model's logic, knowledge management processes act as a transformative mechanism that activates the potential of data. However, their effectiveness is closely dependent on institutional conditions, which is why the model assumes a vertical arrangement in which knowledge processes are located between institutions and data resources.

The third component of the model design is the inclusion of data resources as an input layer, which forms the foundation for the functioning of knowledge processes. The model assumes that data is not a neutral factor, but has significant and varied informational utility, depending on its quality, availability, timeliness, structure and degree of compliance with the analytical requirements of the organisation. Data is therefore both a resource and a constraint, and its nature has a significant impact on the effectiveness of knowledge processes. In the logic of the model, data resources are therefore an element determining the epistemic potential of an organisation, defining the limits of the possible conversion of information into knowledge.

The fourth element of the model refers to competitive advantage as the starting layer, which is the result of the synergistic interaction of institutions, knowledge processes and data resources. The model assumes that competitive advantage cannot be analysed solely as the effect of a company's actions, but as the result of a configuration of systemic, procedural and informational factors. In the logic of the model, competitive advantage is a resultant state that only becomes apparent when all previous layers remain coherent and mutually reinforcing. Therefore, in the model's structure, advantage is placed at the lowest level, as the final link in the sequence of dependencies, rather than as an autonomous category.

A key element of the model's logic is also the assumption that the relationships between the layers are asymmetrical, conditional and hierarchical, rather than linear. This means that institutions influence knowledge processes and data resources, but the latter two do not have the capacity to modify institutions in the short term. Knowledge processes extract value from data, but their effectiveness depends on the properties of the institutions that create the framework conditions. Data, on the other hand, influence the quality of knowledge, but do not determine the directions of regulation that shape its circulation. This asymmetrical relationship architecture forms the logical foundation of the model and makes it possible to capture the mechanisms responsible for the model's didactic transparency, analytical consistency and predictive usefulness.

The model has been designed with a view to its operationalisation in further stages of research, both theoretical and empirical. The model allows for the analysis not only of the levels of dependence, but also of the dynamics of value flow between layers. The systemic nature of the structure means that the model can be used to interpret regulatory changes, evaluate the implementation of data-based technologies, and study the impact of digital transformation on the functioning of enterprises. This makes it a tool with high application potential, capable of adaptation in various sectoral and institutional contexts.

Table 5.

Conceptual model logic – synthetic approach

Model layer	Role in the structure	Impact mechanism	Consequences for further layers
Institutions (regulations, standards, data infrastructure)	Superior layer, determining the systemic conditions for the functioning of enterprises.	Shaping access to data, defining rules for information flow, creating restrictions and incentives.	Sets the limits of the operability of knowledge management processes and determines the epistemic potential of the organisation.
Knowledge management processes (conversion, diffusion, retention, integration)	Transformational layer activating the potential of data.	Transforming information into organisational knowledge, distributing and consolidating knowledge resources.	Determines the quality and consistency of knowledge available for decision-making processes, affects operational efficiency.
Data resources (quality, timeliness, availability, structure)	Input layer determining the organisation's information base.	Providing input material for knowledge processes; modulating informational and analytical value.	It defines the limits of knowledge transformation and influences the organisation's innovation and predictive capabilities.

Cont. table 5.

Competitive advantage (innovation, decision accuracy, process synergy)	The output layer resulting from the interaction of the other elements.	Materialisation of value created by institutions, knowledge and data through improved organisational performance.	Strengthens the adaptability of the system, but does not have a reciprocal effect on institutions (asymmetric relationship).

Source: own study.

The table summarising the logic of the model shows that its structure is based on a consistently organised hierarchy of relationships, in which each layer performs a specific systemic function. Institutions create an overarching framework, defining the operational capabilities of the organisation and setting the boundaries for data flow. Knowledge management processes are a transformative mechanism responsible for giving data epistemic and decision-making significance. Data resources serve as an input layer, determining the value of the results that can be obtained, while competitive advantage materialises the synergistic effects of the entire system.

The presented structure reveals that competitive advantage is a result that cannot be explained in isolation from systemic institutional conditions and the quality of knowledge processes. The model shows the interdisciplinary nature of the relationships, integrating economic, managerial and institutional perspectives, and its architecture allows for a precise analysis of the complex processes characteristic of a data-driven economy.

Thanks to its structured design, the model can serve as both a tool for in-depth theoretical analysis and a basis for empirical applications in research on the determinants of competitive advantage in modern enterprises.

4.3. Recommendation

Based on the proposed model, a set of recommendations relating to its key components can be formulated. First and foremost, the need to adapt organisational knowledge management mechanisms to the existing institutional framework is emphasised, particularly in areas relating to data protection, system interoperability and intellectual property. Harmonising internal procedures with formal regulations helps to reduce the risks associated with information processing and strengthens the possibilities for inter-organisational cooperation, which is an important condition for the functioning of enterprises in a data-driven economy. At the same time, it is advisable to develop knowledge management processes that support the conversion of data into resources of cognitive and operational value, including through mechanisms for the diffusion, retention and integration of knowledge at the operational and strategic levels. Of particular importance is the implementation of tools enabling the automation of information flow, the use of predictive analytics and the systematic documentation of organisational knowledge. At the same time, organisations should take steps to improve the quality of data resources, ensuring that they are up to date, structured and accessible within interoperable information ecosystems. The development of infrastructure based on open data standards, cloud

computing and analytical platforms can significantly increase knowledge productivity and reduce information handling costs. Ultimately, it is emphasised that knowledge management should be treated as an integral part of an organisation's strategic model, rather than a separate process. Only a coherent combination of institutional frameworks, data resource quality and knowledge management processes enables the full exploitation of a company's information potential and provides the basis for building a sustainable competitive advantage in a data-driven economy.

5. Conclusion

The analysis carried out allows us to clearly state that knowledge management in a data-driven economy is a fundamental mechanism determining the ability of enterprises to build sustainable competitive advantages. It has been pointed out that knowledge is not only an organisational resource, but also a complex structure resulting from the interaction of institutions, information processes and the quality of data resources. The conceptual model developed captures this relationship, presenting it as a systemically linked configuration of elements that determine both the effectiveness of decision-making processes and the innovative potential of enterprises.

The conclusions drawn from the analysis confirm the key role of institutions that set the operational framework for organisations and define acceptable forms of data use. Appropriately designed regulations, information infrastructure and institutional stability act as catalysts for knowledge management processes, strengthening their ability to generate organisational value. In turn, the mechanisms of conversion, diffusion, retention and integration of knowledge play a central role in giving data strategic significance, enabling its transformation into a resource of high decision-making utility.

The analysis also emphasises that competitive advantage is not the result of a single process, but rather the result of the synergistic interaction of multiple layers of the system. The effectiveness of knowledge processes depends on the quality of data, and the usefulness of data is only revealed in conditions of institutional coherence. The model thus showed that competitive advantage arises not as the sum of independent factors, but as the result of a coherent configuration of structural and procedural elements.

The study also has practical significance. The results indicate that companies operating in a data-intensive environment should invest in the development of knowledge management systems, striving to improve the quality of information conversion and integration processes. At the same time, it is necessary to monitor regulatory changes and adapt information management models to institutional requirements. The recommendations are universal and can be applied in organisations of different sizes and degrees of digital advancement.

Despite extensive analysis, the study is conceptual in nature, which allows for the identification of several directions for further research. In particular, empirical research on the effectiveness of data conversion processes into knowledge, analysis of the role of algorithmisation in decision-making processes, and assessment of the impact of regulatory policies on the functioning of data ecosystems require further study. The indicated research perspectives may in the future enable the validation of the model in sectoral, regional and inter-organisational conditions, providing in-depth knowledge about the dynamics of competitive advantages in a data-driven economy.

This study is conceptual in nature and has not been empirically validated, which limits the generalisability of the proposed model. The analysis is based solely on secondary literature, which means that its conclusions depend on the availability and interpretation of existing research. Furthermore, the study does not take into account sector-specific differences or organisational factors such as culture, resistance to change or technological maturity. Finally, the rapid development of data management and digital technologies may require future changes to the proposed framework.

In summary, the study presents a coherent and theoretically sound interpretation of knowledge management as a determinant of competitive advantages of enterprises. The conceptual model introduced provides an analytical tool for a systematic understanding of the complex relationships between information, knowledge, institutions and market outcomes. Thus, the article contributes to the development of interdisciplinary scientific discourse on the role of knowledge in the digital economy and provides a starting point for further in-depth research on the mechanisms of data-based advantage.

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STRUCTURAL DETERMINANTS OF AN ORGANISATION'S INNOVATIVE CAPACITY IN THE CONTEXT OF THE TRANSITION TO A KNOWLEDGE-BASED ECONOMY

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Purpose: The aim of this article is to identify and analytically characterise the structural determinants of an organisation's innovative capacity operating in conditions of transition towards a knowledge-based economy. The subject of this approach is the reconstruction of key properties of organisational architecture, resource distribution mechanisms and knowledge management systems that determine the effectiveness of innovation processes in organisations operating in dynamic socio-economic constellations.

Design/methodology/approach: The study is based on a theoretical analysis grounded in the literature on dynamic capabilities, resource-based concepts and knowledge management models. A critical analysis of sources, triangulation of theoretical approaches and a synthetic interpretation of existing scientific research on structural configurations and their impact on organisational innovation were used.

Findings: The analysis indicates that an organisation's innovative capacity is a consequence of complex interactions between resource configuration, organisational structure, knowledge management systems and coordination mechanisms.

Research limitations/implications: The article is theoretical in nature and does not include empirical validation of the presented relationships. However, it indicates directions for further research on the operationalisation of structural determinants of innovative capacity and on the verification of models describing the relationships between organisational architecture and the dynamics of innovation processes.

Practical implications: The conclusions drawn from the article provide a point of reference for managers and designers of organisational structures who seek to strengthen innovation through the rational configuration of resources, the development of advanced knowledge management systems, and the creation of structures capable of flexible recombination of competences.

Social implications: The transformation towards a knowledge-based economy necessitates the systematic monitoring of structural factors that determine an organisation's ability to create new solutions and adapt to technological and social changes.

Originality/value: The article expands on existing scientific achievements through a multifaceted synthesis of structural determinants of innovation and through the presentation of a coherent theoretical model embedded in the current paradigm of the knowledge-based economy.

Keywords: organisational innovation; knowledge-based economy; intellectual capital.

Category of the paper: Research paper.

1. Introduction

The transition to a knowledge-based economy generates multidimensional organisational challenges related to the need to adapt internal structures to conditions characterised by high technological and information dynamics and the growing role of intangible assets. Contemporary organisations operate in systems where knowledge, information and competences are key factors in value creation, determining the ability of individuals to create innovative solutions and build a sustainable competitive position. Innovative capacity is therefore becoming a fundamental category in the analysis of how organisations function in a knowledge-based economy, as it encompasses the ability to generate, absorb, process and apply knowledge in development processes.

Contemporary management literature indicates that organisational architecture and internal coordination mechanisms determine the intensity and quality of innovation processes (Szuszkiewicz, Twardzik, Lubowiecki-Vikuk, 2024). The structural determinants of innovation include the configuration of tangible and intangible resources, knowledge management systems, the degree of organisational flexibility, and the ability of an entity to integrate dispersed competencies. With the development of digitalisation processes and the intensification of network interactions, organisations are under pressure to reconstruct their internal systems, leading to the transformation of traditional hierarchical structures towards modular, heterarchical or hybrid forms (Hauke, Perechuda, 2024). This phenomenon promotes the flow of information and stimulates the development of organisational learning processes, which are central to shaping innovative capacity.

The transformation of the knowledge-based economy also means the need for continuous adaptation to external changes, including technological progress, the globalisation of information flows and the growing expectations of stakeholders. Organisations that strive to maintain a competitive position focus their activities on creating environments conducive to the creation and absorption of innovation. This requires not only the development of intellectual capital, but also the building of systems that integrate knowledge from different segments of the environment. These resources, properly organised within a coherent structure, strengthen the organisation's ability to respond to environmental change and generate new solutions with high application potential.

In view of the above conditions, it is particularly important to identify structural determinants that are directly related to innovation processes. The literature on the subject emphasises that an effective organisational architecture is characterised by a high level of consistency between resource configuration, decision-making mechanisms and the knowledge management system (Zaskórski, Woźniak, 2024). This approach leads to the conclusion that innovative capacity does not result solely from the individual characteristics of an organisation, but is the result of structural and functional synergies that allow for the harmonious integration of knowledge, technology and employee competencies.

Taking the above into account, the aim of this study is to present an analysis of the structural determinants of the innovative capacity of organisations operating in a knowledge-based economy. The article focuses on identifying key organisational components that strengthen innovation processes and determine an entity's adaptive capabilities. From a theoretical perspective, an attempt has been made to reconstruct the relationships between organisational structure, knowledge management systems and resource integration mechanisms, highlighting their importance for the development of organisational innovation. The study expands on existing scientific achievements through a synthetic presentation of structural determinants and their interpretation in the context of current development trends in the knowledge-based economy.

2. Literature Review

The development of the knowledge-based economy has made the issue of organisational innovation capacity a key area of research in management science, organisational theory and institutional economics. In the global literature, the category of innovation is understood as a function of intangible resources, employee competencies, organisational structures and knowledge integration mechanisms (Glaeser, Lang, 2024). Researchers point out that the transformation of economic systems and the intensification of information processes are forcing the reconstruction of organisational architecture towards greater flexibility and adaptability (Ortmann, Sydow, Windeler, 2023).

Classic concepts of knowledge management emphasise that innovative capacity stems from an organisation's ability to create, accumulate, transfer and apply knowledge. Models based on intellectual capital indicate that the prerequisite for generating innovation is the coordination of human, structural and relational resources in a coherent system. The theory of dynamic capabilities developed in recent years clarifies this approach, pointing to the importance of resource recombination processes, perception of changes in the environment and rapid implementation of solutions resulting from new knowledge configurations (Migdadi, 2022).

Research on organisational structures emphasises that traditional, highly hierarchical systems limit the intensity of information flow and hinder the emergence of creative solutions. In response to these limitations, modular, networked and heterarchical structures are emerging, conducive to the parallel generation and integration of knowledge. Organisations are reconfiguring their structures to ensure short decision-making paths, increase the level of autonomy of individuals and strengthen coordination mechanisms (Lazarević-Moravčević, Mosurović Ružičić, 2023).

The literature on knowledge management mechanisms emphasises the importance of information infrastructure and organisational learning processes. Knowledge management systems are a tool for absorbing knowledge from the environment and transforming it into innovative solutions (Skrzypek, Sagan, 2024). Empirical research confirms that the intensity of organisational learning correlates with the potential for innovation in organisations operating in conditions of high technological volatility (Soomro, Mangi, Shah, 2021).

The literature on the knowledge-based economy also draws attention to the importance of technological infrastructure and information resources (Zhang, Xu, Ma, 2023). Organisations operating in conditions of economic transformation show increased sensitivity to the quality of information systems, their ability to integrate data and the effectiveness of information distribution within the organisational structure. Well-organised information systems strengthen an organisation's ability to make decisions based on current knowledge and enable its synthesis in innovation processes (Cheda, 2022).

Research on innovation also draws attention to relational mechanisms, including inter-organisational cooperation, network connections and interactions with scientific and research entities (Sun et al., 2025). The literature indicates that an organisation's ability to absorb knowledge from its environment is strongly related to the intensity of its relationships with external partners and the quality of its systems for integrating external sources of knowledge (Aliasghar, Sadeghi, Rose, 2023).

The accumulated scientific output confirms that an organisation's innovative capacity is a multi-level category, determined by the simultaneous interaction of resources, structure and knowledge management processes. At the same time, researchers point to the need to formulate theoretical models that integrate these areas into a single coherent system, enabling the identification of factors with the greatest impact on innovation in a knowledge-based economy (Mele et al., 2024). This study is part of this trend, providing a synthetic overview of the structural determinants of innovative capacity and identifying the relationships between the main components of organisational architecture. Previous studies have not provided a coherent, empirically verified model of the structural determinants of innovative capacity in a knowledge-based economy. This study fills this gap by proposing a theoretical model that requires further empirical validation.

3. Methods

The methodological design of the study is based on the assumption that the identification of structural determinants of an organisation's innovative capacity requires an analysis covering three complementary levels: (1) the configuration of organisational resources, (2) the architecture of internal structures, and (3) knowledge management mechanisms and

organisational learning processes. Therefore, a multi-stage research procedure was adopted, combining theoretical analysis and expert validation.

3.1. Design of the research tool

In order to systematically capture the structural categories that determine innovation capacity, a structured diagnostic card was developed, comprising a set of measures relating to key dimensions of organisational architecture. The diagnostic card contained items grouped into three modules:

- Module A – Configuration of organisational resources (knowledge resources, technological resources, competence resources, relational resources and structural resources).
- Module B – Organisational architecture (degree of modularity, decentralisation, level of formalisation, scope of decision-making autonomy).
- Module C – Knowledge management mechanisms (systems for the collection, transfer, integration and application of knowledge; intensity of organisational learning processes).

Each module included a set of indicators assessed on a five-point ordinal scale, which is summarised in Table 1.

Table 1.

Structure of the diagnostic card for assessing innovation determinants

Module	Assessment area	Number of indicators	Assessment scale
A	Configuration of organisational resources	12	1 to 5
B	Organisational architecture	10	1 to 5
C	Knowledge management mechanisms	14	1 to 5

Source: own study.

Table 1 presents a summary of the modules and range of indicators used in the diagnostic tool, which forms the basis for the analysis of structural determinants of innovative capacity.

3.2. Expert validation

In accordance with accepted standards of organisational research, a two-stage expert validation was carried out to ensure the substantive correctness of the tool and the adequacy of the indicators used.

- Stage 1 – validation of the tool's content.
Five experts in the field of innovation management assessed the categorical accuracy and semantic consistency of the indicators.
- Stage 2 – structural validation.
Four experts in organisational theory analysed the links between the tool's modules, in particular the relationships between the elements of the organisational structure and knowledge management mechanisms.

The experts' assessments are summarised in Table 2, which allowed for the verification of the degree of consensus.

Table 2.
Results of expert validation (consistency of assessments)

Area of assessment	Number of experts	Consistency of assessments (%)	Interpretation
Relevance of indicator content	5	92	Very high consistency
Structural consistency of the tool	4	88	High compliance
Adequacy of the modular organisation of the tool	5	94	Very high compliance

Source: own study.

Table 2 shows the level of agreement between experts, indicating high stability and correctness of the diagnostic tool structure.

3.3. Analytical process

The analytical process was carried out in three steps, in line with the logic of structural diagnostics:

1. Identification of determining factors.

For each indicator, a weighted average was calculated, assigning greater weight to indicators related to knowledge infrastructure and integration mechanisms.

2. Grouping of determinants by structural categories.

3. A three-level classification was used:

- basic determinants,
- reinforcement determinants,
- synergistic determinants.

4. Reconstruction of the structural dependency model.

Analysis of the links between modules A-C made it possible to establish a hierarchy of determinants and identify the factors of greatest importance for the development of innovative capacity.

The resulting average values of the modules are presented in Table 3, which allows for the assessment of the intensity of key structural areas.

Table 3.
Weighted average values of diagnostic modules

Module	Weighted average	Classification	Significance for innovation
A - Resource configuration	4.28	High	Fundamental determinants
B - Organisational architecture	3.94	Moderately high	determinants of reinforcement
C - Knowledge management	4.52	Very high	synergistic determinants

Source: own study.

Table 3 shows the hierarchy of modules, clearly indicating that knowledge management mechanisms are the most intensive structural component influencing innovative capacity.

3.4. Interpretation techniques used

The results were developed based on the use of two complementary interpretation techniques, the selection of which enabled the reconstruction of a complex system of dependencies determining the innovative capacity of an organisation. The first was a comparative analysis, allowing for a systematic comparison of the intensity of the impact of individual determinants and the identification of their relative strength in the model structure. The second technique used was relational analysis, aimed at recreating the internal architecture of dependencies between organisational resources, internal structure and knowledge management systems. The integration of both techniques made it possible to capture the mechanisms responsible for the formation of feedback loops and synergistic relationships, which constitute the theoretical basis for the model of structural determinants of innovation presented later in this article.

3.5. Theoretical Model

Following the diagnostic procedure and expert validation, a theoretical model of structural determinants of innovation capacity was developed to reflect the relationship between resource configuration, organisational architecture and knowledge management mechanisms. The model presents a hierarchy of determinants and their functions in innovation processes. The structure of the model is based on the assumption that innovation capacity results from the synergistic interaction of resources, structure and integration processes.

The model is summarised in Table 4, which presents three levels of determinants, their organisational nature and the conditions required for their functioning.

Table 4.

Theoretical model of structural determinants of an organisation's innovative capacity

Level of determinants	Characteristics of determinants	Key structural elements	Conditions enabling functioning
Basic determinants (Level I)	Fundamental organisational resources forming the basis for innovation processes	knowledge resources; technological resources; competence resources; relational capital	stable knowledge infrastructure; access to technology; continuous updating of competencies
Strengthening determinants (Level II)	Organisational architecture properties that strengthen knowledge flows and operational flexibility	modularity of structures; decentralisation; low level of formalisation; decision-making autonomy	adaptive operating rules; transparency of processes; strong links between units
Synergistic determinants (Level III)	Mechanisms for knowledge integration and organisational learning generating synergy effects	knowledge transfer systems; knowledge gathering and application processes; organisational learning infrastructure	culture of knowledge sharing; advanced information tools; absorption capacity

Source: own study.

Table 4 presents a model of the theory of innovative capacity, identifying three groups of structural determinants and the conditions for their effective functioning. The model provides a basis for further interpretation of the relationship between resources, organisational structure and knowledge management processes, enabling the reconstruction of the architecture of an innovative organisation.

4. Results

Empirical analysis based on a diagnostic tool made it possible to precisely determine the intensity and hierarchy of structural determinants influencing the innovative capacity of organisations operating in a knowledge-based economy. The results showed clear differences between the three modules: resource configuration, organisational architecture and knowledge management mechanisms. The highest weighted average value was obtained by the module concerning knowledge management mechanisms (4.52), which clearly indicates that the processes of knowledge gathering, integration and application are the most dynamic and influential area in the context of building innovative capacity. The second most intensive module was organisational resources (4.28), confirming that knowledge resources, employee competencies, technologies and relational capital form the basic infrastructure without which innovation processes cannot function. The lowest, though still high, value was obtained by the organisational architecture module (3.94), suggesting that organisational structures play a reinforcing role, intensifying or limiting the use of resources and the potential of knowledge management processes.

These results allowed for the unambiguous assignment of individual modules to the three levels of determinants presented in the theoretical model: basic determinants (organisational resources), reinforcement determinants (organisational architecture) and synergistic determinants (knowledge management mechanisms). The relational analysis also showed the existence of strong relationships between knowledge management processes and resource configuration, which mutually reinforce each other's impact. Knowledge integration mechanisms enable fuller use of organisational resources, while the quality of resources enhances the effectiveness of knowledge absorption and transfer systems.

A moderate but significant relationship between organisational architecture and knowledge management processes was also found. Modular, flexible and decentralised structures promote the intensification of information flow, but their full effectiveness is only revealed when the organisation has a developed knowledge infrastructure and strong integration capabilities. This relationship indicates that organisational structure is not an autonomous factor of innovation; its potential to strengthen innovation processes is conditioned by the efficiency of knowledge management systems.

A hierarchical determinant analysis showed that the most important structural component of an organisation is the knowledge management mechanism, as it generates the greatest synergistic effects, allowing the organisation not only to create new solutions, but also to effectively absorb knowledge from its environment and reconfigure its resources. Only then do the basic determinants, which constitute the resource infrastructure, and the reinforcement determinants related to organisational architecture gain importance. The results therefore indicate the existence of a unidirectional structural hierarchy in which knowledge processes have the greatest impact, followed by resources and, finally, organisational structures.

5. Discussion

The results confirm the thesis that the innovative capacity of organisations in a knowledge-based economy is multidimensional and results from the interactive, rather than linear, impact of resources, structures and knowledge management processes. According to the current literature, knowledge integration systems are a key factor in stimulating innovation processes, which is clearly confirmed by the results presented. Organisations that achieve high results in terms of innovation are those that have developed an infrastructure enabling intensive knowledge flow, rapid processing and effective application in operational practice (Kuźniar, 2021). Knowledge management mechanisms therefore form a basic synergistic system in which the integration of information and experience is a prerequisite for generating new innovative solutions (Aparicio et al., 2023).

The interpretation of the results concerning organisational resources indicates that they constitute the foundation of innovation processes and determine the development potential of an entity. Knowledge and employee competence resources, appropriately linked to technological and relational resources, create a multi-layered basis for the creation of new organisational values (Ben Hassen, 2021). They serve as "input material" for knowledge management mechanisms, which means that innovation is generated not only by the efficiency of processes, but also by the quality and adequacy of resources. This result corresponds with theories of intellectual capital and dynamic capabilities, which indicate that intangible resources are the most important factor for competitiveness in a knowledge-based economy.

With regard to organisational architecture, the results clearly indicate that its role is primarily to strengthen or weaken the impact of knowledge processes and resources. Flexible, decentralised and modular structures increase the intensity of information flow and improve the organisation's ability to integrate dispersed competencies. On the other hand, overly formalised or strongly hierarchical structures can limit innovative activity by slowing down decision-making mechanisms and reducing the effectiveness of knowledge distribution. These results

therefore confirm the importance of organisational architecture, although they also indicate that its effectiveness is secondary to the efficiency of knowledge management processes.

The overall results reveal a clear synergy between resources, structure and knowledge mechanisms. An organisation's innovative capacity does not result from the operation of one of these components, but from the functioning of the entire system, in which knowledge processes integrate resources and enable their effective use in a flexible organisational structure. Therefore, the highest level of innovation is achieved by organisations that are able to simultaneously update resources, reconfigure the structure and strengthen organisational learning processes.

The results of this study also have an application dimension, as they enable organisations to design their internal architecture in a way that is conducive to the generation and absorption of innovation. Practical implications include the need to invest in advanced knowledge management systems, develop employee competencies and maintain organisational structures capable of dynamic resource recombination. The interpretation of the results also indicates that organisations should strive to maintain a balance between the three groups of determinants, strengthening both resources and structures, but making knowledge management mechanisms a central element of their innovation architecture.

6. Summary

The aim of the study was to identify and systematically analyse the structural determinants of the innovative capacity of organisations operating in the context of the transition to a knowledge-based economy. The theoretical analysis and diagnostic tools used allowed for the reconstruction of the hierarchy of determinants and the definition of their role in shaping the organisation's ability to generate and absorb innovation. The results clearly indicate that innovative capacity is systemic in nature and results from the dynamic interaction of resources, organisational structures and knowledge management processes.

The strongest determinant turned out to be knowledge management mechanisms, which perform a synergistic function and have a key impact on the intensity of innovation processes. Organisational resources, including knowledge, competences, technologies and relationships, form the foundation of innovation processes and constitute a basic determinant. The organisational architecture, on the other hand, acts as a reinforcing determinant, intensifying or limiting the organisation's ability to use resources effectively and to implement integration mechanisms. The theoretical model developed as part of the study presents a coherent system of relationships between determinants and is an interpretative tool for assessing the innovative potential of an organisation.

The study contributes to the development of organisational theory by providing a synthetic overview of the structural determinants of innovation and by highlighting the importance of synergy between resources, structure and knowledge. At the same time, the results of the study have practical value, enabling the formulation of recommendations for designing an organisational architecture conducive to generating innovation and utilising knowledge resources. In view of the growing complexity of the economic environment and intensive transformation processes, it is necessary to further deepen research on the structural determinants of innovative capacity, with particular emphasis on organisational learning processes and new forms of work organisation.

The study is theoretical in nature and does not include empirical verification of the presented model, which limits the possibilities of its full generalisation. Furthermore, the use of expert validation may imply subjectivity in assessments, therefore it is advisable to conduct further quantitative and qualitative research to confirm the presented relationships.

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INTERMODAL TRANSPORT IN 2015-2025: A SYSTEMATIC LITERATURE REVIEW

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Purpose: The aim of this article is to analyse the evolution of research on intermodal transport in the years 2015-2025 by identifying the dominant thematic clusters, methodological approaches, and research gaps.

Design/methodology/approach: The study combines a systematic literature review (SLR) with a bibliometric analysis using data retrieved from the Web of Science Core Collection. Out of 1,071 articles, 152 publications were analysed. The study includes (1) article selection based on the PRISMA protocol, (2) manual preparation and cleaning of 902 keywords in Excel, and (3) creation of co-occurrence maps, clusters, and time visualizations in VOSviewer.

Findings: The study revealed an interdisciplinary research area within intermodal transport, including four main thematic clusters that reflect both the traditional foundations of intermodal transport and emerging research directions.

Research limitations/implications: The review is limited to publications indexed in the Web of Science, published between 2015 and 2025 and written in English, and the analysis did not include a methodological assessment of individual articles. Future research could broaden the database scope and apply methodological triangulation.

Practical implications: The findings contribute to a better understanding of how intermodal transport systems may evolve to become more efficient, resilient, and environmentally sustainable.

Originality/value: This article is one of the few comprehensive analyses that combine SLR and bibliometric methods to assess 11 years of research on intermodal transport. It offers new insights into the thematic evolution of the field, identifies methodological patterns, and highlights research gaps.

Keywords: intermodal transport; bibliometric analysis; systematic literature review; VOSviewer.

Category of the paper: Research paper/Literature review.

1. Introduction

Intermodal transport – defined as the movement of goods in a single loading unit using at least two different modes of transport without handling the goods themselves – has for many years been regarded as a key component of transport systems (OECD, 2001; Crainic, Kim, 2006; European Commission, 1997; Gajdzik et al., 2023; Fikus, Liszka, 2024). Intermodality has become not only an alternative to road transport but also one of the pillars of strategies for sustainable development, integration, and supply chain optimization. The role of intermodal transport is growing both in practice and in research, which is reflected in the expanding body of academic work. As the volume of studies on intermodal transport increases, so does the need for syntheses that consolidate existing knowledge and highlight emerging research directions – an observation that motivated the development of this article. Intermodal transport plays a particularly important role in maritime logistics, where the efficient connection between seaports and inland transport modes determines the fluidity of global supply chains. Moreover, intermodality significantly contributes to reducing the environmental impact of transport systems, enabling a shift towards more sustainable transport solutions.

Early approaches in the literature on intermodal transport focused primarily on issues related to the integration of transport modes, and it was crucial to understand the “basics” of intermodality – definitions, system components, relationships between modes of transport, and the impact on transport efficiency, such as the review of intermodal transport by Hanssen and Mathisen, 2014, or earlier in the study by Bontekoning et al., 2004. Early considerations of intermodal transport also included issues related to the organization of intermodal transport (Mindur, Hajdul, 2011), the location of terminals, and transport planning (Pierre et al., 2004; Caris et al., 2008) and the problem of supporting intermodal transport policy decisions (Macharis et al., 2011; Mostert et al., 2017), or aspects of the costs of intermodal transport networks (Janic, 2007; Bierwirth et al., 2012) and cost efficiency (Jarżemskienė, Jaržemskis, 2010). An important analytical element in the literature is research on cargo consolidation models (Bierwirth et al., 2012), innovative elements combining production planning and intermodal transport in supply networks (Meisel et al., 2013), and service quality in intermodal terminals (Abramović et al., 2012).

In recent years, research directions have expanded considerably. New studies increasingly focus on the integration of logistics chains in an international context, taking into account environmental aspects and the multidimensional implications of intermodality. Attention should also be paid to the literature addressing intermodal transport in the context of international issues, such as Polish-Ukrainian relations (Jacyna-Gołda et al., 2024), regional perspectives (Przybylska et al., 2023), environmental considerations (Ferguson et al., 2025; Bairam, Shadab, 2025), environmentally oriented modal choice (Bayramoğlu et al., 2025), analyses of maritime–rail systems (Abu Aisha et al., 2024), and cost modelling (Kovalenko

et al., 2024). Recent studies also highlight innovation and digital solutions supporting planning processes (Zajac et al., 2025), the use of Internet of Things technologies to predict cargo arrival times (Balrogis et al., 2025), and route selection supported by machine learning methods (Xinyu, 2025). Research increasingly addresses tactical planning that incorporates logistical factors affecting planning efficiency (Vieira, 2024; Chupin et al., 2025), the location of dry ports as key components of intermodal systems (Li et al., 2025), as well as business models for intermodal transport of perishable goods, with particular emphasis on digitalisation and stakeholder cooperation (Barranco et al., 2025). An important extension of this research stream is the treatment of terminals as key nodes coordinating logistics within intermodal networks, as emphasised by Monios and Bergqvist (2025).

This study provides a comprehensive review of the literature on intermodal transport, with particular emphasis on the dominant research trends and changes occurring between 2015 and 2025. The work is based on a bibliometric analysis of 152 scientific publications from the Web of Science database, covering the period 2015-2025. The aim was to systematize the most important and reliable research results and to identify potential areas requiring further exploration. The analysis was conducted in accordance with the systematic literature review (SLR) approach, including the stages of defining research questions, identifying and selecting publications, and synthesizing their evaluation according to the PRISMA model.

The following sections of the article will present the detailed research methodology, including the literature search and selection procedure and the tools used for data analysis. This will be followed by a presentation of the research results, including a visualised bibliometric network prepared in VOSviewer, showing key thematic clusters and the evolution of research over time. The next section will cover the discussion of the results and interpretation of the obtained relationships. The conclusion will present the prospects for future research as well as the limitations of the study.

2. Methodos

2.1. Dynamics of Academic Literature Development

The dynamic growth of academic output confirms the increasing interest in the field of intermodal transport. As indicated by an analysis of publications indexed in the Web of Science database, the number of articles devoted to intermodal transport has been steadily rising – from fewer than 10 publications per year in 2015-2017 to as many as 24 publications in recent years. The growth in citation counts is even more pronounced, highlighting the increasing relevance of this topic in the international academic discourse. The peak citation level recorded in 2024 suggests that this research area has reached a stage of academic maturity and resonates strongly with other fields (Figure 1).

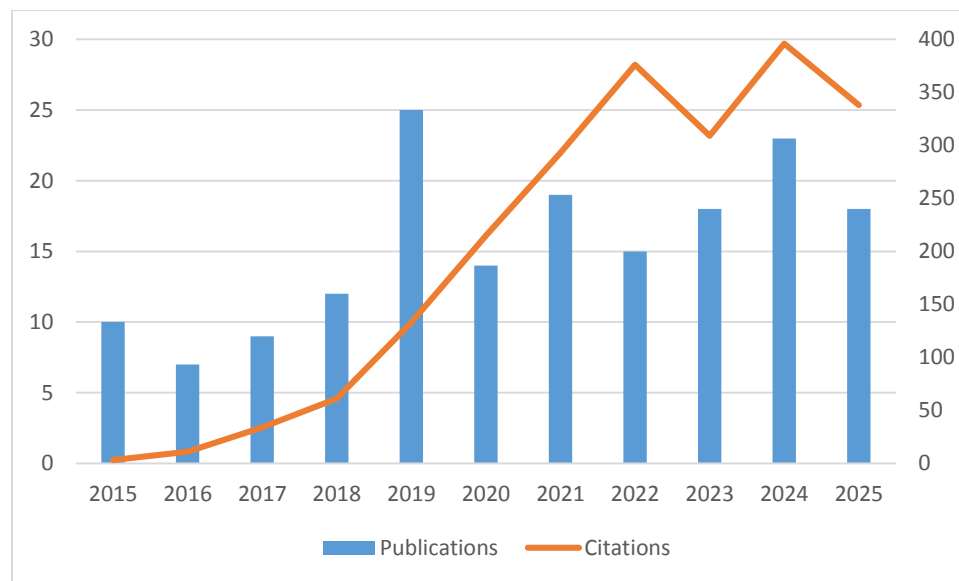


Figure 1. Total number of publications and citations by year.

Source: own elaboration based on Web of Science.

The field of intermodal transport research is highly diverse and covers topics ranging from technical analyses and optimization processes, through environmental perspectives and modern technologies, to political and systemic approaches. However, there is a lack of up-to-date review studies in the literature that would capture the dominant research directions, emerging thematic clusters, and potential analytical gaps in a structured and visual manner.

2.2. Research protocol

The study is based on the methodology of a systematic literature review (SLR), following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta – Analyses) guidelines as one of the established standards (Liberati et al., 2009). This approach enables a deeper understanding of the methodological aspects of the research domain, and as scholars emphasize – a rigorous and well-executed review provides a solid foundation for knowledge development (Synder, 2019). Systematic literature reviews are characterised by high methodological value in academic research (Višić, 2022). SLR allows for the identification of key publications, their thematic classification, and critical assessment (Mengist et al., 2020; Mohamed Shaffril et al., 2022), which makes this method particularly suitable for introducing research on intermodal transport.

In this article, a PRISMA flow diagram (Preferred Reporting Items for Systematic Reviews and Meta – Analyses) was used to visualise the publication selection process (Page et al., 2021). Although the review was not formally registered and some elements of the PRISMA 2020 checklist (e.g. assessment of risk of bias in primary studies) were not applied, the structure of the diagram was adapted to ensure transparency and a systematic approach to the processes of searching, selecting, and excluding articles (Figure 2).

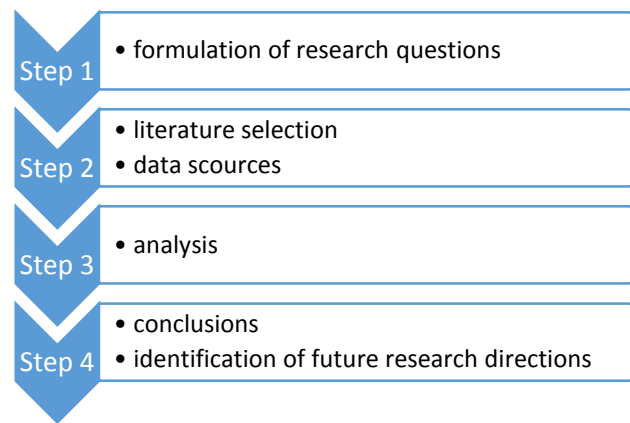


Figure 2. Research protocol.

Source: own elaboration.

2.3. Research questions

As highlighted in the literature, clearly formulated research questions constitute the foundation of a systematic literature review – they define the scope of the review, guide the process of searching and selecting publications, and frame the analysis of the findings. In evidence-based reviews, the formulation of an appropriate research question determines the relevance of selected sources and the overall quality of the review (Ziemba et al., 2025; Bellucci et al., 2022).

Accordingly, to address the overarching objective, three key research questions were formulated:

1. What are the main thematic clusters in the literature on intermodal transport?
2. Which methodological approaches and perspectives dominate research on intermodality?
3. Which areas require further exploration?

2.4. Data collection

The analysis covered publications indexed in the Web of Science database for the years 2015-2025. The choice of 2015 as the starting point of the examined period stems from the noticeable shift in the development dynamics of the sector, as well as its convergence with the launch of several EU initiatives related to sustainable development. Including data up to 2025 makes it possible to capture the most recent trends, including the growing interest in topics such as digitalization, EU climate policy, and geopolitical considerations. Recent years have also seen an intensive expansion of research on supply chain resilience, which has been reflected in the literature on intermodal transport. Thus, the selected time horizon allows for a more comprehensive representation of development dynamics and provides an up-to-date basis for identifying both dominant and insufficiently explored research directions.

The keyword search used the term TS = ("intermodal transport"), applied to titles, abstracts, and author keywords. A total of 1071 publications were identified. Subsequently, in accordance with the methodology of the systematic literature review (SLR), predefined inclusion and exclusion criteria were applied.

Inclusion criteria:

- language of publication: English,
- document type: scientific articles,
- publication period: 2015-2025,
- Web of Science categories: Transportation; Transportation Science & Technology; Management; Green & Sustainable Science & Technology; Economics; Environmental Sciences; Environmental Studies; Operations Research & Management Science,
- availability: All Open Access.

After applying the above restrictions, 169 publications remained in the Web of Science database.

In the subsequent selection phase, to ensure substantive relevance, the titles, keywords, and abstracts of all 169 articles retained after applying the predefined criteria were analysed. The selection process was conducted manually to minimise the risk of systematic bias and to ensure high thematic consistency of the review.

The main exclusion criterion in this stage was the direct relevance of the study to the issue of intermodal transport, particularly in the context of topics such as the integration of transport modes, intermodal terminals, logistics, benefits and barriers of modal shift, infrastructure strategies, EU policy, and the digitalization of processes within intermodal freight transport.

Following this stage, 17 publications were excluded, as their thematic focus despite occasional terminological overlaps did not correspond to the core objectives of the study. The primary reasons for exclusion included:

- tourism and passenger-oriented topics, such as studies on public transport, urban mobility, or tourist travel (e.g. "urban tourism and intermodal public transport"),
- air transport and its integration with airport access, without reference to classical freight intermodality (e.g. "air-rail intermodality", "airport access"),
- pandemic related research (COVID-19) focusing on changes in trade structure, urban logistics, or personal mobility,
- environmental or health-related studies, in which intermodality appeared only as a minor component of broader analyses on biodiversity, public health, or energy systems,
- topics unrelated to logistics, such as ride-sharing, car-sharing, biodiesel, electric vehicles, etc.

Figure 3 below presents the detailed process of identifying, selecting, and qualifying publications in accordance with the PRISMA structure, including each stage of dataset reduction and the number of studies excluded at each step.

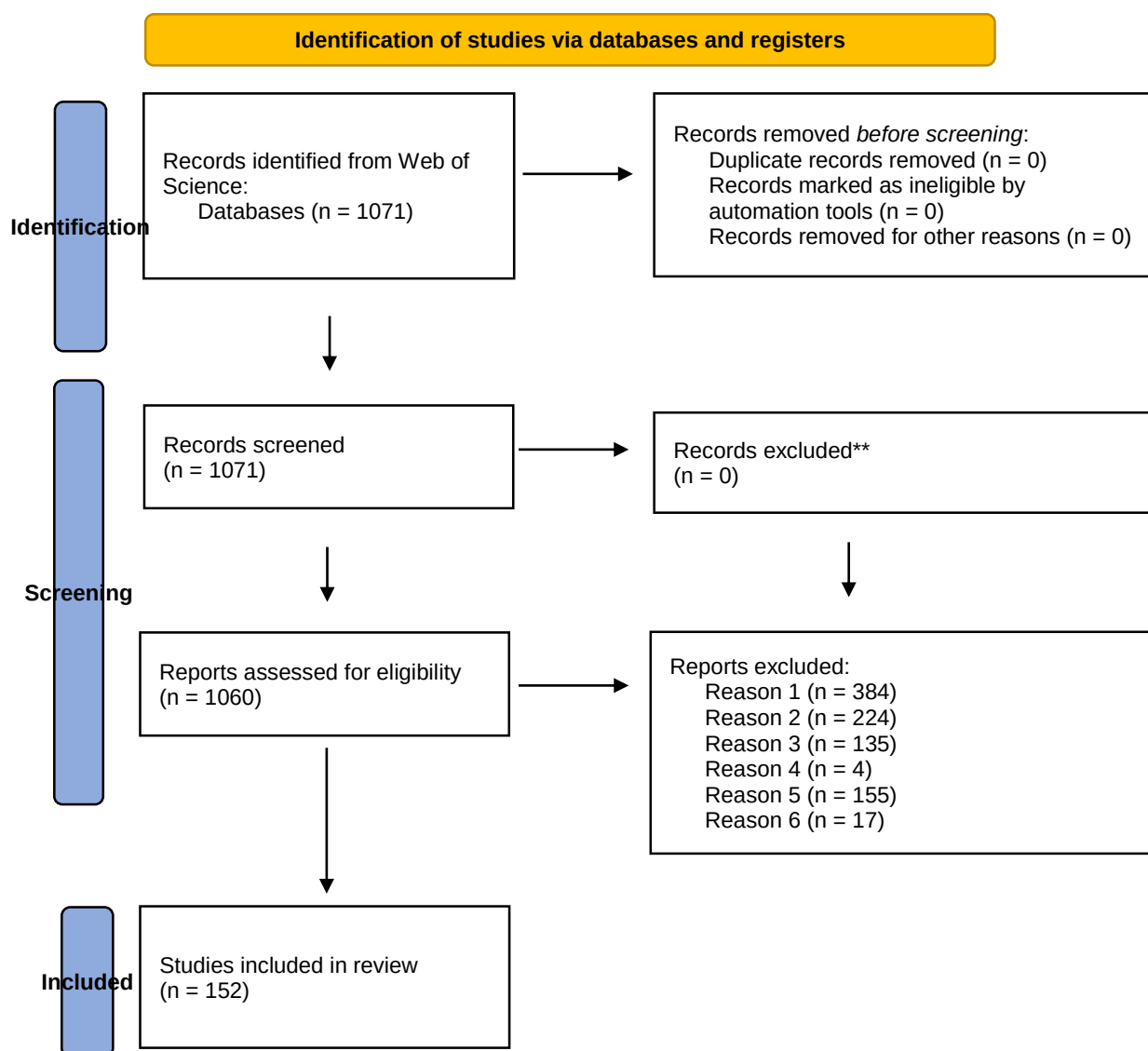


Figure 3. Flow diagram of the study selection process based on the PRISMA model.

Source: own elaboration.

3. Data analysis

3.1. Keywords

As a preliminary stage of the analysis, before conducting a bibliometric analysis in VOSviewer, a separate, fully independent data preparation stage was created, involving the manual compilation of keywords in Excel spreadsheets. In order to identify research trends in

the field of intermodal transport and sustainable logistics, a set of 902 keywords obtained from the records of 152 publications in the Web of Science (WoS Core Collection) database was analyzed. The data preparation process consisted of several stages:

1. exporting metadata from the WoS database,
2. aggregating all keywords from publication records,
3. manually cleaning the collection of duplicates, spelling errors, and semantic variants (e.g. intermodal transport/intermodal transportation),
4. standardization of keyword terminology,
5. preparation of the final set for frequency and co-occurrence analysis.

The preliminary exploratory stage also included the preparation of a graphical summary illustrating the evolution of selected keywords across the analysed publications. These charts complement the subsequent bibliometric analyses conducted in VOSviewer and provide an initial overview of the key terms appearing in studies published between 2015 and 2025.

The first chart (Figure 4) presents the total number of occurrences of the Top 10 keywords throughout the entire study period. The most frequently used term is *intermodal transport*, which confirms its central role in the analysed academic discourse. Significant prominence is also given to terms related to rail transport, ports, logistics of transshipment centres, supply chains, and modal shift. This overview highlights the broad thematic scope of the research area and confirms its interdisciplinary nature.

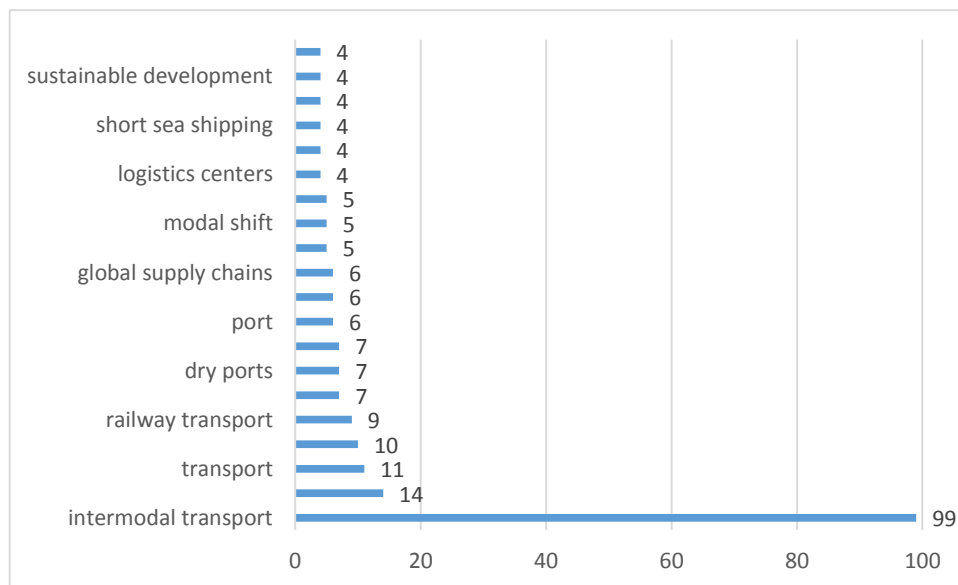


Figure 4. Top 10 keywords.

Source: own elaboration.

The second chart (Figure 5) illustrates the number of occurrences of the Top 5 most frequently used terms between 2015 and 2025. The term *intermodal transport* clearly dominates, with its frequency markedly exceeding the remaining categories (blue line). A gradual increase in interest is also observable in topics such as sustainability, multi-criteria decision making, and railway transport.

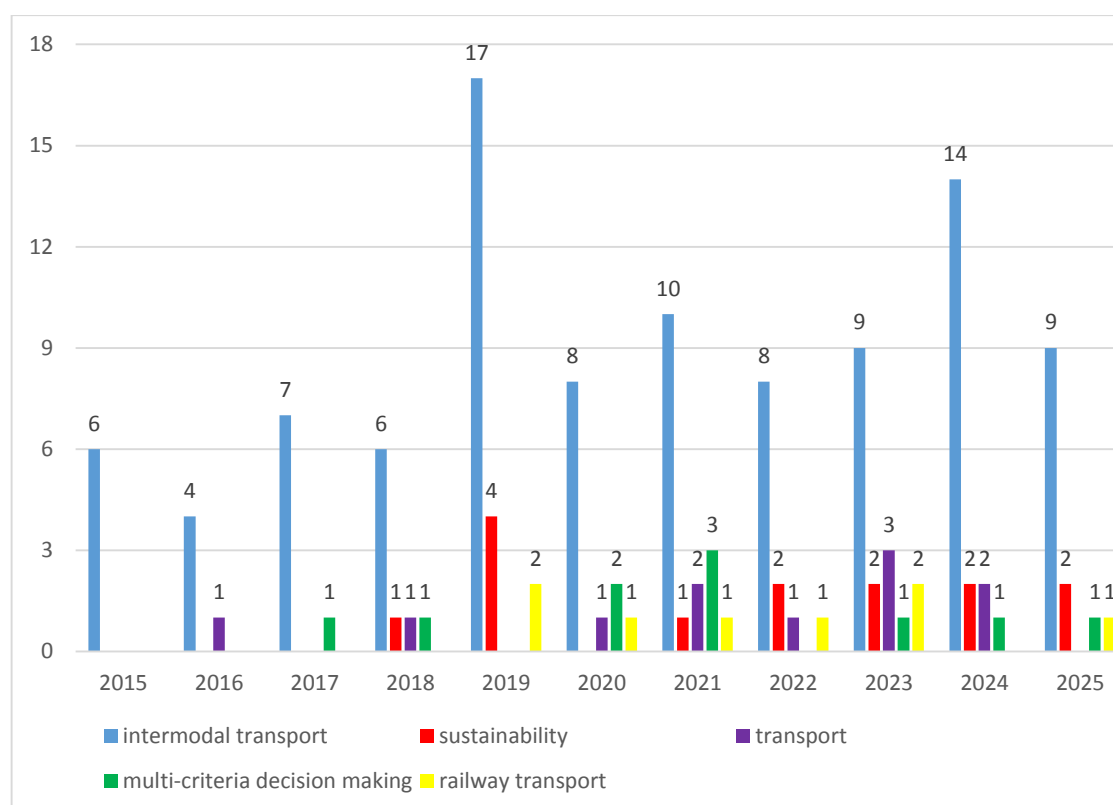


Figure 5. Top 5 most frequently used keywords in 2015-2025.

Source: own elaboration.

3.2. Bibliometric Analysis

For the bibliometric analysis, which encompassed 152 articles from the Web of Science database selected according to the predefined criteria, the VOSviewer software was used. This enabled:

- co-occurrence analysis,
- co-authorship analysis,
- overlay visualization.

3.2.1. Keyword Co-occurrence Analysis

To identify the dominant research themes, a keyword co-occurrence analysis was conducted using the VOSviewer software. The analysis covered 152 articles from the Web of Science database selected according to the predefined criteria. Based on the results, a conceptual map was generated (Figure 6), illustrating the cluster structure of the terms most frequently appearing in the analysed publications.

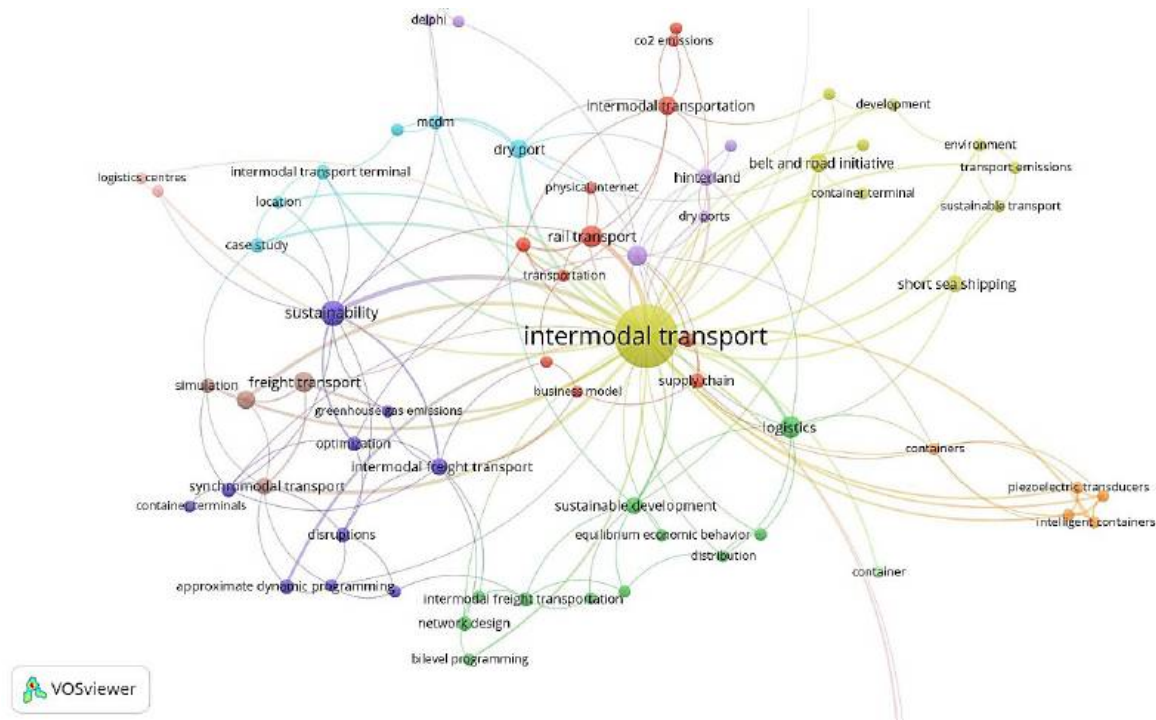


Figure 6. Keyword co-occurrence clusters in intermodal transport research.

Source: own elaboration.

The red cluster is centred around terms such as: *business model*, *CO₂ emissions*, *environmental impact*, *governance*, *intermodal transportation*, *physical internet*, *rail transport*, *road transport*, *supply chain*, *transport*, and *transportation*.

The green cluster, comparable in size to the red cluster, includes terms such as: *bilevel programming*, *cost-benefit analysis*, *distribution*, *equilibrium economic behavior*, *foreign trade*, *integration*, *intermodal freight transportation*, *intermodal terminals*, *logistics*, *network design*, and *sustainable development*.

The purple cluster is represented by keywords such as: *approximate dynamic programming*, *container terminals*, *disruptions*, *greenhouse gas emission*, *intermodal freight transport*, *optimization*, *reinforcement learning*, *resilience*, *simulation-optimization*, and *sustainability*.

The yellow cluster is represented by terms such as: *Belt and Road Initiative*, *container terminal*, *development*, *digitalization*, *environment*, *infrastructure*, *intermodal transport*, *short sea shipping*, *sustainable transport*, and *transport emissions*.

3.2.2. Overlay Visualization

Figure 7 presents a conceptual map generated using the overlay visualization technique, which reflects the average publication year of individual terms in the analysed literature. The colour scale corresponds to chronological progression – from purple, indicating older publications, to yellow, representing the most recent ones.

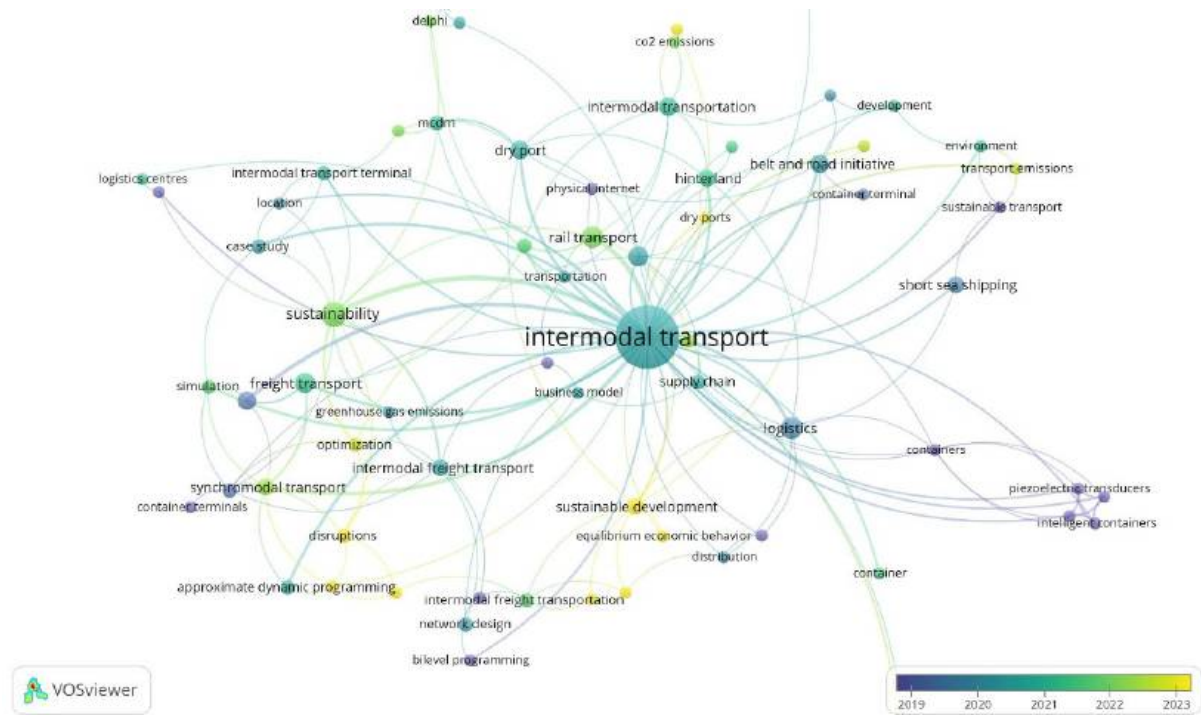


Figure 7. Overlay visualization of keyword co-occurrence by publication year.

Source: own elaboration.

The visualization shows that earlier studies, primarily from 2019-2020, cluster around classical concepts such as *logistics*, *container terminal*, *distribution*, *short sea shipping*, and *location*. Their prominence corresponds to traditional research areas focused on the structure of intermodal systems.

In contrast, newer publications from 2022-2023 highlight more advanced and multidimensional topics, including *disruptions*, *resilience*, *reinforcement learning*, *carbon tax*, and *simulation-optimization*. These themes align with research on machine learning, resilience, and sustainability, indicating a shift in research emphasis toward predictive analyses, planning, and optimization.

3.2.3. Co-authorship Analysis

The next stage of the analysis involved co-authorship visualisation, aimed at identifying the authors who collaborate most frequently in research on intermodal transport. The results generated using VOSviewer indicate that the author collaboration network is relatively dispersed, with limited connections between researchers (Figure 8).



Figure 8. Co-authorship network of researchers in intermodal transport.

Source: own elaboration.

The most notable collaborative relationship is formed by Mladen Krstić and Snežana Tadić, whose work focuses on intermodal transport, environmental aspects, and the selection of technologies and their impact on intermodal transport efficiency. Their studies employ methods such as multi-criteria decision-making models, the Delphi method, DEMATEL, Axial Distance-Based Aggregated Measurement (ADAM), fuzzy FARE, and fuzzy CODAS.

Another researcher who stands out is Sabine Limbourg, who collaborates with several different authors and is a co-author of a substantial number of publications. Her work focuses, among other topics, on instruments for managing intermodal transport, strategic-level analyses of modal split between road, intermodal rail, and inland waterway transport under various economic and environmental policies, as well as studies addressing economic and environmental objectives in relation to the benefits of intermodal transport.

4. Results

The analysis conducted in this study reveals substantial thematic and methodological diversity in research on intermodal transport. Combining bibliometric analysis with a systematic literature review made it possible to adopt a multidimensional perspective on the development of intermodal transport between 2015 and 2025. The results of the keyword co-occurrence analysis indicate a clearly formed structure of four main thematic clusters, reflecting

both classical themes and the foundations of intermodality, as well as new research topics arising from, among others, environmental and technological challenges.

The review of 152 publications and the keyword analysis provide insight into the methodological approaches and research perspectives present in the literature. Most notably, modelling and optimization approaches dominate. Scholars frequently apply models for terminal location, transport planning, transport simulation, and cost analysis. This is consistent with the nature of operations research, which for decades has constituted a key component in the development of intermodality, as reflected by keywords found within the clusters, such as *bilevel programming*, *cost–benefit analysis*, *simulation–optimization*, and *network design*.

In addition, the importance of modern technologies such as machine learning is increasingly evident. Environmental analyses focusing on emissions and energy efficiency also remain essential. These research trends correspond to EU climate objectives and global tendencies toward sustainable transport. Equally important are topics related to international corridor integration, geopolitical conditions (e.g. Poland-Ukraine relations), port development, and the role of terminals as logistics nodes. The literature also includes case studies, which complement the review with a practical dimension.

5. Discussion

The results of this study are consistent with previous literature but also reveal a number of developments that have not been systematically synthesized so far. Authors such as Hanssen and Mathisen (2014) and Bontekoning et al. (2004) have explored the fundamentals of intermodal transport in their research. The cluster structure described in this paper confirms that these topics remain at the core of the field, as reflected in the green cluster, which brings together research on network modeling, optimization, and design. At the same time, bibliometric mapping indicates a clear thematic expansion towards environmental, digital, and resilience-oriented perspectives, which is consistent with recent work on sustainability (Ferguson et al., 2025; Bayramoğlu et al., 2025) and technological innovation (Zajac et al., 2025; Balrogis et al., 2025). Compared to previous reviews, this study offers a broader and more integrated overview of eleven years of research. Identifying four clusters provides a structured representation of how research topics are organized within a given field. Importantly, this structure helps explain why certain research areas become priorities.

Based on the identified trends, several potential future research directions can be distinguished. First, there is a growing need for studies on the resilience of intermodal networks to disruptions. Topics such as *resilience* and *disruptions* appear with increasing frequency, yet they require deeper investigation, particularly in the context of accelerating geopolitical changes. Another important research direction concerns digital solutions and smart

technologies, given that the full integration of intermodal transport relies heavily on advanced technologies, standardisation, and international cooperation. Furthermore, the literature still lacks comprehensive models enabling effective management of intermodal transport networks.

Additional research is also needed on the environmental dimension of intermodality, including detailed emission assessments and analyses of the impact of climate policies. The literature on intermodal transport is currently undergoing a transformation – from technical and optimization-oriented approaches toward systemic, digital, and environmental perspectives. The results of this study indicate that future research will require broader interdisciplinary integration, drawing on economics, engineering, and transport policy, among other fields.

6. Limitations

Despite the broad scope of the analysis and the application of the SLR methodology based on the PRISMA framework, this study has several limitations that should be taken into account when interpreting the findings:

1. The analysis relies exclusively on publications indexed in the Web of Science database, which may result in the omission of certain literature, industry reports, and publications not indexed in major databases.
2. The selected time frame (2015-2025) – although justified by the development dynamics of the field—does not include earlier, historically oriented works that could further enrich the context of the evolution of the intermodality concept.
3. The choice of keywords was limited yet purposeful, aiming to clearly delineate the boundaries of the review.
4. The keyword co-occurrence analysis in VOSviewer is based on terminology assigned by the authors of the publications. Differences in indexing practices or terminology used (e.g. combined transport, multimodal logistics) may lead to partial discrepancies in classification.
5. The study did not include a methodological assessment of individual articles, such as data quality or model reliability.

Despite these limitations, the findings provide a coherent overview of the structure of research on intermodal transport and constitute a solid basis for further comparative analyses and in-depth case studies.

7. Summary

In summary, intermodal transport is currently one of the key areas of development in contemporary research, and scientific literature confirms its growing role. This review provides a systematic overview of the current state of knowledge in the years 2015-2025, while also identifying areas requiring further exploration.

The bibliometric analysis revealed four main thematic clusters that reflect the diversity of research approaches and the development of interdisciplinary discourse in the field of intermodality. Although the cluster map itself does not assess the completeness of research in each area, the identified clusters offer a useful framework for interpreting research gaps. Future research directions reflect topics that appear in clusters but are not yet widely developed, and the analysis confirms that intermodal transport is becoming the subject of interdisciplinary research. References to disruptions and resilience are concentrated within a single cluster, suggesting that resilience research continues to form a specialized rather than a broadly integrated research stream at the intermodal transport network level. Similarly, terms related to digitization and modern technologies appear in clusters, but only in a scattered manner, indicating growing but still limited interest. Environmental issues, on the other hand, appear in several clusters, and their dispersion suggests that research in this area needs to be more precisely targeted, given the importance of sustainable development in transport.

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**THE ECONOMIC DIMENSION OF THE DEFINITION
OF AN ENTERPRISE CONTAINED IN ARTICLE 55(1)
OF THE CIVIL CODE FROM THE PERSPECTIVE
OF THE POSSIBILITIES AND METHODS OF ASSESSING ITS VALUE**

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Purpose: The aim of the article was to present the assumptions of the definition of an enterprise, taking into account the criteria for its valuation from the perspective of Article 55 of the Civil Code. The main assumption was the interpretation of legal assumptions and the application of appropriate methods of enterprise valuation, taking into account its definition established in legal regulations. The article pointed out discrepancies between the analysis of legal provisions and the established trend in economic science. In addition, differences in the application of selected valuation methods in the context of the components of an enterprise specified in Article 55(1) of the Civil Code were indicated.

Design/methodology/approach: The article discusses valuation methods in the context of various court proceedings, the factors determining their appropriate selection, and presents an index analysis based on data published by the Central Statistical Office relating to selected profitability indicators. Based on balance sheet data for various sectors of enterprises, the fixed asset productivity ratio was estimated and the share of fixed assets in total assets was estimated, in line with the assumption that enterprises generating income from fixed assets should be valued mainly using asset-based methods. The aim of the analysis was to identify these groups of enterprises on the basis of the relevant PKD sections and to assess profitability thresholds, assuming that the companies under review were in good financial condition. Companies whose operations were at risk or in a state of economic bankruptcy were excluded from the study. The companies were identified on the basis of the results of an index analysis and a cluster analysis using the k-means method. The analyses were performed using Statistica 13 software.

Findings: According to findings based on the literature on the subject, the greatest dilemma regarding the substance of Article 55(1) of the Civil Code is the lack of an unambiguous definition of valuation methods. The results of the study show that the highest profitability was achieved in the motor vehicle and motorcycle trade and repair sector, construction and education. Cluster analysis confirmed the similarity measures obtained in relation to the established profitability, indicating that asset-based methods should be used primarily in relation to the main manufacturing sectors.

Originality/value: The study is primarily addressed to persons involved in the valuation of companies in relation to ongoing court proceedings. An important aspect established on the basis of the analyses carried out is the reference of selected groups of companies to specific methods of determining the value of a company in the absence of relevant legal provisions.

Keywords: company value, valuation methods, asset-based company valuation methods, civil law.

Category of the paper: Scientific paper.

1. Introduction

The current value of a company has various reference points from a practical perspective, both in terms of legal and economic sciences. The definition of value depends on many aspects. It was specified in detail in Interpretation Note No. 5 developed by the Association of Property Appraisers in 2011 and modified in 2024. According to point 4.3 of Interpretation Note No. 5, the purpose of valuing a company, its organised part or share in a company may be to determine its value, inter alia, for the purposes of: purchase, sale, composition, bankruptcy or liquidation proceedings, merger or division of companies, capital increase or redemption of shares, determination of the value of assets held by funds, civil and legal proceedings, tax proceedings, financial reporting, creditworthiness and credit security verification, insurance, compensation and control of the value of capital invested by the owner in the enterprise. Given the nature and scope of court proceedings, valuations are most commonly used in practice to determine value in enforcement proceedings, bankruptcy proceedings, determining the value of an enterprise for the purpose of estimating the parties' joint property, and also to a large extent in relation to compensation cases.

This publication focuses on discussing the definition of an enterprise and the essence of enterprise valuation in selected civil law proceedings relating to the established definition formulated in Article 55(1) of the Civil Code. The key research problem was an attempt to answer the question: Is every enterprise subject to the same valuation criteria depending on the type of jurisdictional proceedings, and what are the reasons for the differences in the approach to its value? Is the value of an enterprise determined by applicable legal regulations or is it only an element of financial analysis, and which valuation methods are closest to selected sectors of the economy, taking into account the balance sheet status of selected enterprises?

2. Definition of an enterprise from the perspective of its valuation methods.

The essence of an enterprise has been clarified in numerous legal acts. The key definition is included in Article 55(1) of the Civil Code. According to this provision, an enterprise is an organised set of intangible and tangible components intended for conducting business activity. This definition clarifies the components of an enterprise, while also indicating the scope covered by the valuation. These include: designations identifying the enterprise or its

separate parts, ownership of real estate or movable property, including equipment, materials, goods and products, as well as other property rights to real estate or movable property, rights arising from real estate lease and tenancy agreements, and rights to use real estate or movable property arising from other legal relationships. The article then lists receivables, rights arising from securities and cash, concessions, licences and permits, patents and other industrial property rights, copyrights and related property rights, trade secrets, and books and documents related to the conduct of business.

Some of the above-mentioned components represent direct value for the company, while others are a kind of goodwill, i.e. value created by customers, expressed mainly through the value of its revenues. It should be noted that each element of the specified assets is estimated using different methods depending on the type of proceedings and using different valuation methods. It also depends on the form of business activity. "Currently, there is no single definition of market value; there are as many definitions as there are national and international associations and entities that set valuation standards (Morri, 2019). The definitions of an enterprise contained in the literature allow us to conclude that "it is not possible to fully implement the postulate of standardising the concept of an entrepreneur throughout the legal system (Materna, 2009), and thus to assign specific valuation methods to selected proceedings corresponding to the definition of an enterprise formulated in Article 55(1) of the Civil Code.

The legal definition of an entrepreneur indicates that an entrepreneur is a natural person, a legal person or an organisational unit that is not a legal person, to which a separate act grants legal capacity (Article 4 of the Civil Code). "The definition of an enterprise expressed in Article 55(1) of the Civil Code separates this concept from the entity to which the enterprise belongs and emphasises its tangible and intangible components and their organisational and functional combination (Szczygieł, 2019). Therefore, the methods of determining the value of an enterprise will depend on the industry and the method of keeping accounting records and access to data on the business activity. In the case of a sole proprietorship, the form and possibility of determining the value of the enterprise becomes crucial. The dilemmas associated with the valuation of a small enterprise mainly concern proceedings relating to the division of marital property, which is currently becoming one of the key elements of such cases. Article 55(1) of the Civil Code does not specify how to determine the value of such enterprises.

With regard to property matters, it is crucial to determine the nature of the spouses' joint property and their contribution to the development of the business, both tangible and intangible. Formal employment is not always taken into account, and sometimes assistance with accounting, work organisation or relief from household duties is sufficient, provided that it can be established that these activities have translated into an increase in the value of the business and an increase in the number of customers. The involvement of the other spouse in the business is key to the assessment. The possibility of such involvement depends on the type of business activity. Pursuant to Article 31 § of the Family and Guardianship Code, upon entering into marriage, a statutory community of property is established between the spouses by operation of

law, which includes property acquired during its duration by both spouses or by one of them. Personal property (Article 33 of the Family and Guardianship Code) includes property acquired before the establishment of the statutory community, acquired by inheritance or donation, as well as property used exclusively by one of the spouses. If a business develops during the marriage and its value increases, the value of that business is taken into account when estimating the expenditure from the joint property on personal property.

A common problem is determining both the capabilities and involvement of one of the spouses in the development of the business and whether that person has increased the value of the business. For the analyst, the key factors are the choice of valuation method, the nature of the business, and whether other persons were involved in the business. The definition formulated in Article 55(1) of the Civil Code does not provide any significant guidance on how to determine the value of a business. Usually, in property proceedings, the aim is to use property-based valuation methods, which do not always relate to the type of business activity. In practice, the content of the article does not specify the method of valuing the enterprise in such cases. This means that the valuation method is up to the financial analyst, who is obliged to make a preliminary assessment of the enterprise's situation.

A common problem arises: Does Article 55(1) of the Civil Code allow for the valuation of a company using different methods? Valuations formulated in the available standards applicable to financial analysts, i.e. Interpretation Note No. 5 on subsequent guidelines amended in July 2024. Therefore, this article does not allow for the selection of the appropriate valuation method without a detailed financial and economic analysis of the entity being valued. According to NI 5, the methods of valuing an enterprise go beyond the criteria set out in Article 55(1) of the Civil Code. The very definition of an enterprise formulated in Article 55(1) of the Civil Code indicates valuation using asset-based methods, aiming to estimate the value of the enterprise's fixed assets in the form of determining the value of real estate, movable property and specific rights. This article narrows the definition of an enterprise mainly to the value of fixed assets. This article does not indicate how to separate and value other intangible assets that are not included in intangible assets, such as: the intangible value of an enterprise (goodwill) and the demand for the enterprise's products valued according to income methods.

According to section 8.3.1 of NI 5, one of the methods of valuing a business is the income method based on projections of future economic income. The provision only indicates a set of components necessary to conduct business activity, defining an enterprise in the objective sense as an organised set of both tangible and intangible components, defining rights of various forms (Supreme Court ruling, 2009-2010). The period of revenue projections, as defined in economic science, specifies that the financial forecast should be based on the following conditions: in the case of enterprises whose operation is limited in time, the projection should coincide with the period of planned activity, and with regard to the possibility of continuing the activity for an unlimited period of time, the projection should cover the period preceding the phase of full maturity of the operating activity, characterised by the achievement of stable income.

Article 55(1) of the Civil Code does not refer in any way to the possibility of using income preceding the conduct of the valued activity, especially since in cases concerning the division of joint property, the composition of the property is determined at the moment of termination of joint ownership, i.e. on a specific date. When analysing the situation of many companies operating after the date of division, it should be noted that their financial condition is not at risk, so there are no grounds for determining the value of their assets using asset-based methods, as is often requested by the parties in such proceedings. Asset-based methods are based on the valuation of individual assets and liabilities (p.8.2.1 NI 5). They do not take into account the synergies between the components of the enterprise related to their organised use. In practice, they mainly cover enterprises whose balance sheet value consists largely of fixed assets, mainly tangible fixed assets, which generate a large part of the enterprise's revenue.

The case law of common courts points to the principles of valuation selection, indicating that the rejection of the income approach and, consequently, the necessity to apply the asset approach is primarily due to the fact that the income approach departs from the asset substance of the enterprise (Judgment of the Court of Appeal of 9 November 2013).

In order to assess their value, it is important to determine how much revenue the company generates from tangible fixed assets. These issues can be assessed by calculating the turnover (productivity) ratio of fixed assets, and above all, the productivity of tangible fixed assets, measured by the ratio of net sales revenue to the average value of tangible fixed assets. In addition, it is important to determine the share of fixed and current assets in total assets in order to determine which part of the assets finances the business. Determining the relationship between asset categories is one of the elements of assigning the appropriate valuation method.

3. Methods

The study uses the following method of secondary survey analysis, which is a retrospective analysis. In addition, documents and available sources on valuation methods were analysed. The analyses were supplemented with statistical analyses. The study formulated the following research hypothesis: What is the predictor of profit generated by a company in relation to specific companies, and which companies can be valued using asset-based methods?

In order to determine the appropriate valuation method, the results of analyses presented by the Central Statistical Office published in 2024 (GUS, 2024) were taken into account. The analyses determined values for the following indicators: return on fixed assets and the ratio of fixed assets to current assets. The results were analysed taking into account the relevant section and PKD name according to the classification presented in Table 1. The classification criteria were profitable enterprises (<0.1; <1.2; <2.5; < 5.10; 10 and above) and by the number of people employed in 2024.

Loss-making enterprises were excluded from the study. Cluster analysis was used to present the results in order to categorise the collected observations into smaller sets with similar profitability ratios, taking into account the assumed criteria. The cluster analysis was performed in the Statistica 13 software environment. The study estimated the share of fixed assets in total assets and the return on fixed assets ratio. The return ratio in terms of determining the amount of net profit per unit of value of assets involved in the company. This ratio is called the return on assets ratio. It provides information on the efficiency of fixed asset utilisation in an enterprise. The higher the value, the better the enterprise is rated (Kowalak, 2022).

The purpose of the analysis was to determine which companies are suitable for the income approach and which can be valued using the adjusted net asset method. In practice, the adjusted net asset method is most often used for companies that finance their operations with fixed assets. These are most often manufacturing companies or companies that derive profits from fixed assets, e.g. hotels. The high share of the indicated indicators made it possible to determine which of the main activities should also be valued using asset-based methods and for which it is more appropriate to use income-based methods. The analyses included companies according to the PKD (Polish Classification of Activities) sections listed in Table 1.

Table 1.

List of PKD sections included in the research sample selection

A	AGRICULTURE, FORESTRY, HUNTING AND FISHING
B	MINING AND QUARRYING
C	MANUFACTURING
D	ELECTRICITY, GAS, STEAM, HOT WATER AND AIR CONDITIONING SUPPLY
E	WATER SUPPLY; SEWAGE AND WASTE MANAGEMENT AND REMEDIATION ACTIVITIES
F	CONSTRUCTION
G	WHOLESALE AND RETAIL TRADE; REPAIR OF MOTOR VEHICLES, INCLUDING MOTORCYCLES
H	TRANSPORT AND STORAGE
I	ACCOMMODATION AND FOOD SERVICE ACTIVITIES
J	INFORMATION AND COMMUNICATION
K	FINANCIAL AND INSURANCE ACTIVITIES
L	REAL ESTATE ACTIVITIES
M	PROFESSIONAL, SCIENTIFIC AND TECHNICAL ACTIVITIES
N	ADMINISTRATIVE SERVICES AND SUPPORT ACTIVITIES
P	EDUCATION
Q	HEALTH CARE AND SOCIAL ASSISTANCE
R	ACTIVITIES RELATED TO CULTURE, ENTERTAINMENT AND RECREATION
S	OTHER SERVICE ACTIVITIES

Source: Central Statistical Office, Local Data Bank, GUS - Bank Danych Lokalnych, 21.10.2025.

The findings obtained on the basis of the research also made it possible to determine which elements of the enterprise specified in Article 55(1) of the Civil Code can be valued using the indicated methods. The share of fixed assets in the balance sheet total allows us to conclude that not all methods can be applied to all types of activities. ‘A high valuation obtained using the income method in relation to valuations obtained using other methods indicates the high efficiency of the company's team (Matusiak, 2015),’ but also the possibility of generating

income through current assets and the intangible nature of the business. In practice, "the oldest methods of company valuation are asset-based methods, which use fixed assets as the basis for determining value. The balance sheet is used as the starting point for determining value. However, this method does not take into account future prospects, the overall condition of the company, problems within the entity, or the state of the economy, i.e. all information not included in the balance sheet" (Prędko, 2015). The productivity ratio allows us to determine the range of methods that we can use when selecting the appropriate valuation method.

4. Results

According to the research conducted using the method of comparing the return on fixed assets in key sectors of activity, the highest profitability was observed in the following sectors (Table 2): retail trade, including repair of motor vehicles and motorcycles, construction, and education (Table 3). As part of the analysis, a cluster analysis was also prepared using the Ward's method, with Euclidean distances used as a measure. "Cluster analysis is a technique that allows the detection of interdependencies between objects. Its main purpose is to identify relatively homogeneous groups (clusters, classes) that form an interpretable classification of the analysed objects. Cluster analysis therefore allows the creation of clusters of objects that are as similar as possible within groups and diverse between groups. The first stage of cluster analysis is the selection of objects and variables, as well as the normalisation of their values. Next, a distance measure and classification method must be selected.

The next stage is to determine the number of clusters and evaluate the classification results. The final step is to describe and interpret the clusters obtained (Domagała, 2019). In terms of Euclidean distances, the measure of similarity within feature vectors was provided by companies operating in the fields of healthcare, social assistance, transport and warehousing, information and communication, real estate, electricity generation and supply, construction, education, and wholesale and retail trade. The smallest Euclidean distance was 0.7867 and the largest was 9.6247.

Table 2.*Return on fixed assets ratio for enterprises by profitability levels for selected PKD sections*

	profitability (0:1)	profitability (1:2)	profitability (2:5)	profitability (5:10)	profitability after 10
Agriculture, forestry, hunting and fishing	b.d	5,5	5,96	10,5	20,5
Mining and quarrying	b.d	5,1	b.d.	15,3	40,63
Manufacturing	1,63	6,33	9,7	22,16	43,36
Electricity, gas, steam and air conditioning supply	1,3	33,6	12,93	13,6	11,13
Water supply, sewerage, waste management and remediation activities	0,26	1,56	2,93	6,26	24,86
Construction	2,56	10,66	19,83	35,73	58,13
Wholesale and retail trade, repair of motor vehicles including motorcycles	5,8	14,3	28,36	46,7	75,8
Transport and storage	2	7,5	12,76	23,2	21,23
Accommodation and food service activities	1,1	3,3	7,9	15,56	16,7
Information and communication	2,06	7,86	16,76	8,6	18,9
Financial and insurance activities	b.d	6,5	1,26	3,5	8,8
Real estate activities	0,4	1,16	1,83	3,33	9,5
Professional, scientific and technical activities	3,13	12,63	27	26,93	19,66
Administrative and support service activities	4,7	10,2	13,13	30,23	19,56
Education	2	18,16	10,2	47,03	65,66
Health care and social assistance	2,33	10,1	9	16,33	43,13
Cultural, entertainment and recreational activities	1,3	26,93	b.d.	12,33	28,3
Other service activities	1,66	7,6	29,86	27,9	45,46

Source: Own study based on data published by the Central Statistical Office, Financial results of enterprises in 2024, 02.11.2025.

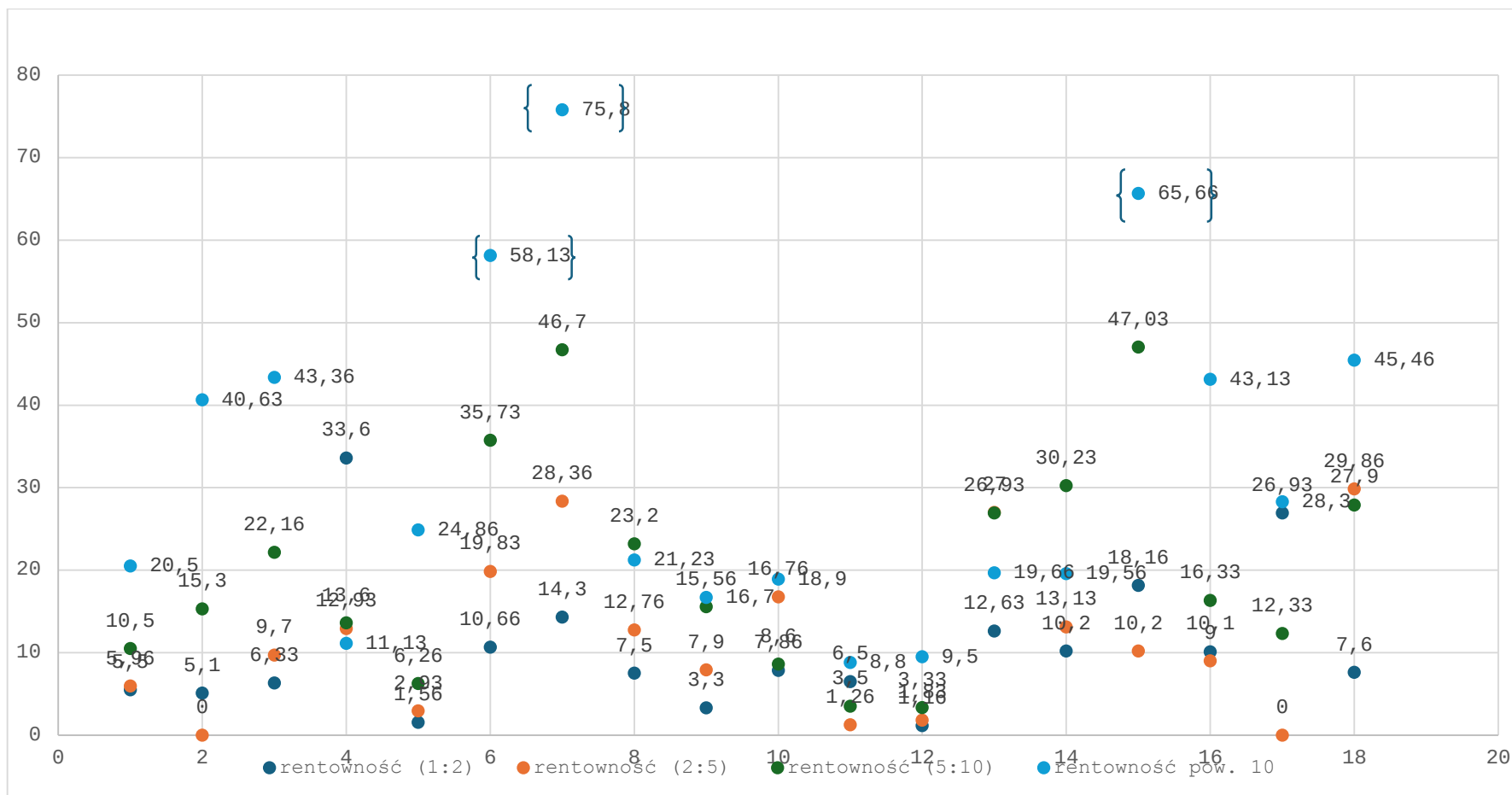


Figure 1. Profitability levels for industries according to PKD (Polish Classification of Activities).

Source: own research.

Table 3.*Share of fixed assets in total assets for enterprises by profitability levels for selected PKD sections*

	profitability (0:1)	profitability (1:2)	profitability (2:5)	profitability (5:10)	profitability after10
Agriculture, forestry, hunting and fishing	b.d.	48,48	57,8	56,29	62,56
Mining and quarrying	b.d.	42,11	b.d	54,05	48,26
Manufacturing	41,91	41,64	53,37	44,23	43,36
Electricity, gas, steam and air conditioning supply	70,28	16,34	52,5	54,28	79,98
Water supply, sewerage, waste management and remediation activities	87,63	74,24	79,01	79,27	63,39
Construction	26,38	23,12	24,41	27,84	27,31
Wholesale and retail trade, repair of motor vehicles including motorcycles	29,12	29,06	32,54	30,66	30,35
Transport and storage	53,16	46,65	54,29	50,95	70,84
Accommodation and food service activities	68,4	69,66	66,4	71,13	78,67
Information and communication	47,18	40,23	42,05	67,91	66,1
Financial and insurance activities	b.d.	7,94	55,92	41,35	57,04
Real estate activities	74,74	76,98	77,07	75,97	69,08
Professional, scientific and technical activities	28,72	22,61	23,59	37,28	49,97
Administrative and support service activities	31,84	49,65	56,27	43,66	61,13
Education	51,82	57,17	60,62	39,84	44,45
Health care and social assistance	60,02	50,14	65,12	65,75	58,39
Cultural, entertainment and recreational activities	61,53	56,87	b.d	70,55	67,23
Other service activities	46,57	39,63	31,06	47,94	53,36

Source: Own study based on data published by the Central Statistical Office, Financial results of enterprises in 2024, 02.11.2025.

Table 4.

Agglomeration process for the analysed sections carried out using the Word method (Euclidean distances)

Euclidean distance connections	Obj. No 2	Obj. No 3	Obj. No 4	Obj. No 5	Obj. No 6	Obj. No 7	Obj. No 8	Obj. No 9	Obj. No 10	Obj. No 11	Obj. No 12
,7867573	health care and social assistance										
,8174480	activities related to real estate market services										
1,130617	Activities related to accommodation and catering services										
1,340543	Activities related to accommodation and catering services	Information and communication									
1,566633	other service activities										
1,890237	administrative services and support activities		Activities related to accommodation and catering services								
2,241015	health care and social assistance	Transport and warehousing		Information and communication							
2,649618	other service activities	education	Wholesale and retail trade, repair of motor vehicles including motorcycles								
3,741691	other service activities	education	Activities related to accommodation and catering services								
3,788911	health care and social assistance	Transport and warehousing	Wholesale and retail trade, repair of motor vehicles including motorcycles	Information and communication	activities related to real estate market services						

Cont. table 4.

3,992282	other service activities	education	Activities related to accommodation and catering services	professional, scientific and technical activities							
5,068548	health care and social assistance	Transport and warehousing	Activities related to accommodation and catering services	Information and communication	activities related to real estate market services	Production and supply of electricity, gas, steam	Production and supply of electricity, gas, steam				
9,624718	health care and social assistance	Transport and warehousing		Information and communication	activities related to real estate market services	Production and supply of electricity, gas, steam	Production and supply of electricity, gas, steam	Construction	other service activities	education	Wholesale and retail trade, repair of motor vehicles including motorcycles

Source: own research.

The study confirmed that asset-based methods are most appropriate for companies with high profitability and those whose operations involve a large share of fixed assets in the structure of the assets under review. A high share of fixed assets is particularly important. The analysis confirmed that the value of fixed assets argues in favour of using asset-based methods. Among the examined companies that are similar to each other, not in bankruptcy and in good financial condition, the following can be included: companies operating in the areas of construction, real estate, transport and trade, as well as education. The k-cluster analysis confirms the results of previous analyses using ratio methods.

5. Discussion

The analysis of the profitability of fixed assets based on data from the Central Statistical Office confirms the current trend that companies with a high share of fixed assets and their productivity are taken into account in asset-based valuation methods. In practice, companies with a high share of fixed assets are not always those that generate income from tangible fixed assets. As indicated in the literature, ‘asset-based methods are very useful in companies that rely heavily on the use of their assets to create enterprise value. These mainly include oil and gas companies or entities with large amounts of real estate’ (Kiess, Soprenzetti, 2024, p. 202).

Other studies point to the types of assets that should be valued using the adjusted net asset method, i.e. one of the asset-based methods, including office buildings, production facilities, assembly lines, and inventories of materials and products. It is pointed out that the advantage of using the adjusted net asset method is the condition and suitability of the assets for use (Zarzecki, 2020, p. 58).

Currently, the scope of activities of enterprises that use asset-based methods for income-based valuation is indicated, specifying what methods these should be without specifying which enterprises they should be. The research conducted made it possible to group these enterprises and classify them according to those for which asset-based methods are most appropriate. Other studies, without reference to specific groups of enterprises, indicate that this method is most appropriate for entities that generate returns on their assets rather than on their use. The authors of the study emphasise that the adjusted net asset method may also be appropriate for enterprises in the early stages of development, without a significant financial history (IFRS, 2016, p. 25). For some companies, market trends such as changes in consumer behaviour, changes in industry dynamics or technological advances can significantly affect the value of the company (Viversity Online Courses, 2025).

When applying asset-based methods, the financial standing of the company, its profitability and, above all, its productivity determine the choice of the appropriate method. It should be noted that the studies used are among the few currently conducted that refer to specific groups

of companies. Most analyses in the field of studies on determining the value of a company are primarily a polemic with the current state of affairs in this area. The research confirmed the hypothesis that manufacturing companies from sectors with a high share of fixed assets have the highest productivity in terms of fixed assets. However, not all manufacturing companies can be included in this group, which means that the remaining group of companies operating in the manufacturing sector can also be valued using income-based methods. Currently, the biggest limitation in conducting this type of analysis is access to data. The value of companies can be determined when access to reporting data is available. The possibilities for valuing small and medium-sized enterprises are still limited due to the fact that these companies use simplified accounting, which is not available to most analysts.

6. Conclusion

Currently, in practice, we encounter types of enterprises for which we have knowledge of valuation methods. Often, these types of enterprises are the subject of property proceedings. They include both small specialist companies, often run by a single person, and micro-enterprises without significant tangible fixed assets. On the other hand, large enterprises or small companies whose productivity is mainly dictated by fixed assets are subject to valuation. Differences in the approach to valuation often result solely from tangible fixed assets, as not every company has to generate income of a similar value, having only a larger share of fixed assets in its total assets. The research conducted confirmed that the selection of asset-based methods for valuation is primarily dictated by the productivity generated by selected fixed assets.

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THE IMPORTANCE OF CORPORATE INCOME TAX IN MUNICIPAL BUDGETS IN POLAND IN THE YEARS 2019-2024

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Purpose: The main purpose of the publication is to present the importance of corporate income tax in municipal budgets in the years 2019-2024.

Methodology: Analysis of data from the library of the Central Statistical Office.

Findings: The assessment results obtained from the analysis of municipal budget revenues indicated the significant importance of corporate income tax, which in turn affects the implementation of a wide range of tasks by local government units. During the analyzed period, significant changes occurred in the legal system affecting the revenues of local government units, in particular, several important amendments were made to the corporate income tax law, which in turn poses a challenge for municipalities in terms of taking actions for the effective management of budget revenues.

Research limitations/implications: The article contains a preliminary study. In the future it is planned to conduct additional quantitative and qualitative research.

Originality/value: The publication discusses the significance of corporate income tax in the revenues of municipalities in Poland. The analysis took into account own revenues, grants, and subsidies. The article also includes selected legal changes in corporate income tax that have impacted the growth of municipal revenues from this source.

Keywords: taxes, corporate income tax, public finance, local government units.

Category of the paper: Research paper.

1. Introduction

Corporate income tax (CIT) in the Polish tax system is characterized by the fact that the revenue from this tax is divided between the State Treasury and local government units (LGUs), i.e., municipalities, counties, and voivodeships. The fundamental basis of a municipality's autonomous economy is its budget. In turn, the condition for municipalities' ability to carry out the public tasks assigned to them is ensuring that these units receive an appropriate share of public revenues. The division of public revenues on an institutional level requires that the municipalities' own tasks be financed through the revenues allocated to them. CIT is one of the most important sources of income for municipalities. Revenue from this tax constitutes

a significant part of a municipality's budget and allows for the implementation of many public tasks. The amount of revenue from CIT depends on many factors, such as the number of enterprises operating in the municipality, their income, and the size of employment. The aim of this study is to assess the significance of corporate income tax (CIT) in shaping municipal budget revenues in Poland in the years 2019-2024, taking into account the differences between municipalities with cities having county rights and municipalities without such cities. A specific objective is also to identify trends, structural changes, and macroeconomic conditions that influenced the size and share of CIT revenues during the analyzed period. The following hypotheses were proposed in the study:

- H1: The share of corporate income tax (CIT) in the own revenues of municipalities in Poland shows an upward trend in the years 2019-2024.
- H2: CIT revenues are more significant for cities with county rights than for municipalities without such cities.
- H3: Fluctuations in CIT dynamics in the years 2019-2024 are strongly related to the economic situation, including the COVID-19 pandemic and legislative changes.
- H4: Municipalities with a higher number of enterprises and a higher level of economic development achieve relatively greater fiscal benefits from CIT.

2. Corporate Income Tax – Theoretical Aspects

Corporate Income Tax – CIT belongs to the category of income taxes that burden positive business results (income, profit). It is a tax with a significantly shorter history than the personal income tax. A separate corporate income tax, or as it is often called, a tax on companies, was introduced in 1909 in the USA. In Europe, France was the pioneer, where in 1948 legislation was introduced that clearly distinguished the taxation of individuals from the taxation of corporations. Other European countries began to adopt similar tax solutions only in the 1960s (Krajewska, 2012).

In Poland, corporate income tax was introduced for the first time in 1989 (Ustawa z dnia 31 stycznia 1989 r....). It was one of the elements of a comprehensive reform of the Polish tax system, carried out in the early 1990s by all transforming economies. The need to align regulations regarding legal entities with the provisions of personal income taxation, introduced under the Act of July 26, 1991, on personal income tax, was the reason for implementing significant changes, which were reflected in the provisions of the Act of February 15, 1992, on corporate income tax, hereinafter referred to as the CIT Act (Ustawa z dnia 15 lutego 1992 r...). The provisions of the Act do not apply to:

- a) income from agricultural activity, except for income from special sectors of agricultural production, unless the determination of income is required for the purpose of identifying income exempt from income tax,
- b) income from forest management within the meaning of the Act on Forests,
- c) income resulting from activities that cannot be the subject of a legally effective agreement,
- d) income (profits) of shipping entrepreneurs taxed with the tonnage tax.

According to Article 1 of the Corporate Income Tax Act, taxpayers of this tax are legal persons and organizational units without legal personality, except for partnerships without legal personality: civil-law partnerships, general partnerships, professional partnerships, limited partnerships, and limited joint-stock partnerships (their partners are subject to tax obligations under the Personal Income Tax Act). This means that, in effect, the subjective scopes of the two income tax acts complement each other, i.e., taxpayers under the Personal Income Tax Act are natural persons, including partners in partnerships without legal personality (Ustawa z dnia 15 lutego 1992 r...)

Taxpayers having their registered office or management board within the territory of the Republic of Poland are liable to taxation on the entirety of their income, irrespective of the location in which such income is generated. Taxpayers lacking a registered office or management board within the territory of the Republic of Poland are subject to taxation solely on income derived from activities carried out within the territory of the Republic of Poland. In the case of the latter category of taxpayers, who are obliged to maintain accounting records in Poland, where determination of income based on such records is not feasible, income shall be ascertained through estimation, applying an income-to-revenue coefficient, e.g., 5% for activities in wholesale or retail trade, and 10% for construction, assembly, or transport services (Ustawa z dnia 15 lutego 1992 r...).

The subject of corporate income tax, analogous to personal income tax, is income, understood as the excess of revenues over the costs of their generation. The starting point for the calculation of income, and thus for the determination of the tax, is revenue. Revenue constitutes the broadest economic category, encompassing all measurable financial effects of conducting any activity (Kosikowski, Ruśkowski, 2008).

In cases where a taxpayer has incurred a loss in a given tax year, the amount of this loss may be used to reduce income in each of the subsequent five consecutive tax years, provided that the reduction in any given year does not exceed 50% of the loss amount. In the case of income from participation in the profits of legal persons (e.g., dividends), as well as income of foreign entities derived from so-called license fees (e.g., interest), the subject of taxation is the revenue. Taxable revenues particularly include received money, monetary equivalents, exchange rate differences, or the value of goods, rights, or other benefits received free of charge or partially for consideration. Revenues related to business activities and special sectors of

agricultural production also include amounts due, even if not yet actually received, after deducting the value of returned goods and any granted rebates. For the determination of the date of revenue recognition, the general rule is that revenue becomes due on the date of delivery of goods, disposal of property rights, or performance of a service, including partial performance, but no later than the date of issuance of an invoice or settlement of the respective receivable. In the case of services settled over billing periods, revenue is recognized on the last day of the billing period specified in the contract or invoice (but not less frequently than once a year). This approach is also applied to determine the date of revenue recognition for the supply of electricity, heat, and piped gas. With respect to revenues for which the above rules do not apply, tax regulations provide that the date of revenue recognition is the date of receipt of payment (Ustawa z dnia 15 lutego 1992 r...).

As a general rule, the tax base is constituted by income after deduction, inter alia, of any donations made for specific purposes, subject to a 10% limit in relation to such income. Expenditures incurred by the taxpayer on research and development activities may also be deducted from the tax base. The Act specifies the types of expenditures that qualify for such deductions (so-called "qualified expenditures"). The upper limit of deductions is 50% of these expenditures and depends on both the type of expenditure and the size of the taxpayer. For taxpayers commencing their business activity, a special refund mechanism has been introduced in cases where the income achieved is lower than the deductible amount. The corporate income tax rates are as follows (Ustawa z dnia 15 lutego 1992 r...):

- a) 19% of the tax base,
- b) 9% of the tax base for revenues (income) other than from capital gains – in the case of taxpayers whose revenues in the tax year do not exceed, in Polish zlotys, the amount equivalent to €2,000,000, converted at the average euro exchange rate published by the National Bank of Poland on the first business day of the tax year, rounded to the nearest 1000 PLN.

A taxpayer shall not apply the 9% tax rate on the tax base in the tax year in which the business was commenced, nor in the immediately following tax year, if the taxpayer was established (Ustawa z dnia 15 lutego 1992 r...):

- a) as a result of a transformation, merger, or division of taxpayers, with the exception of the transformation of a company into another company,
- b) as a result of the transformation of an individual entrepreneur conducting business in their own name or of a partnership lacking legal personality,
- c) by legal persons, natural persons, or organizational units without legal personality who contributed, as capital to the taxpayer, a previously conducted enterprise, an organized part of an enterprise, or assets of that enterprise whose total value exceeds the equivalent in Polish zlotys of at least €10,000, converted at the average euro exchange rate

announced by the National Bank of Poland on the first business day of October of the year preceding the tax year in which these assets were contributed, rounded to the nearest 1000 PLN, with the value of these assets calculated in accordance with the provisions of Article 14, as appropriate,

- d) by legal persons, natural persons, or organizational units without legal personality contributing, as non-monetary contributions to the taxpayer's capital, assets obtained by such persons or units as a result of the liquidation of other taxpayers, provided that such persons or units held shares (stocks) in the liquidated taxpayers,
- e) by legal persons, natural persons, or organizational units without legal personality, if in the tax year in which the taxpayer was established, and in the immediately following tax year, a previously conducted enterprise, an organized part of an enterprise, or assets of that enterprise were contributed to its capital with a total value exceeding the equivalent in Polish zlotys of €10,000, converted at the average euro exchange rate announced by the National Bank of Poland on the first business day of October of the year preceding the tax year in which these assets were contributed, rounded to the nearest 1000 PLN, with the value of these assets calculated in accordance with the provisions of Article 14, as appropriate.

3. Municipal Share in Corporate Income Tax Revenues

With regard to the municipal share in corporate income tax revenues, pursuant to the Act on Municipal Revenues and the principles of their subsidization in the years 1991-1993, as well as the amendment to the Act on Local Government, the municipal share amounted to 5% of corporate income tax revenues. The percentage share was thus maintained at the same level as provided for in the Act on Municipal Revenues. The Act on the Revenues of Local Government Units in the years 1999-2003 preserved the municipal share in corporate income tax revenues at this same level. A new development was the introduction and allocation of shares in corporate income tax revenues to counties and voivodeships, which began to operate in 1999. The prevailing Act on the Revenues of Local Government Units increased the percentage rates of municipal shares in corporate income tax revenues. The share in corporate income tax revenues from taxpayers with their registered office within the municipality amounted to 6.71% (Ustawa z dnia 13 listopada 2003 r...).

If a corporate income taxpayer maintains a branch (or establishment) located within the territory of a local government unit other than that corresponding to its registered office, a portion of the income attributable to its share in corporate income tax revenues is transferred to the budget of the local government unit in whose territory the branch (or establishment) is

situated, proportionally to the number of employees based on employment contracts. In the case of a corporate tax group, the provisions of Article 10, paragraph 1, shall apply correspondingly to the companies comprising the corporate tax group, as well as to the branches (or establishments) of those companies. For a corporate income taxpayer conducting business through a foreign establishment located on the territory of the Republic of Poland, a portion of the income attributable to its share in corporate income tax revenues is transferred to the budget of the local government unit in whose territory the employees are engaged, based on employment contracts, by the taxpayer or by its foreign establishment, in proportion to the number of persons employed by the taxpayer or by that foreign establishment within the territory of the Republic of Poland (Ustawa z dnia 13 listopada 2003 r...).

Corporate income taxpayers are obliged to prepare and submit information to tax offices, containing a list of branches (or establishments) and the number of employees working under employment contracts in each branch (or establishment), indicating the local government units within whose territory these branches (or establishments) are located. The financial resources received by municipalities from corporate income tax (CIT) are allocated to various purposes. Municipalities enjoy broad autonomy in deciding how to utilize these funds. Most commonly, these funds are directed toward (<https://www.podatki.gov.pl/cit/>):

- a) infrastructural investments (such as road construction, renovation of public buildings, or modernization of water supply networks),
- b) economic development, e.g., through supporting local entrepreneurship, creating new jobs, or promoting the region,
- c) education and culture, including funding for schools, kindergartens, libraries, theaters, and other cultural institutions,
- d) social and health purposes, such as social assistance, care for the elderly, or preventive programs.

Income taxes are regarded by financial law doctrine as among the most ideal taxes of contemporary states. Both the personal income tax (PIT) and the corporate income tax (CIT) constitute the core of modern tax systems.

4. Methods

The study is quantitative in nature, based on the analysis of public data and statistical data. The following research methods were applied: The empirical material was based on data from the Local Data Bank (BDL GUS), the Ministry of Finance (reports of local government units), and statutory data on municipalities' shares in PIT and CIT taxes. The collected data included: total municipal revenues, own revenues of municipalities, the structure of own revenues

(including PIT and CIT), and revenue dynamics broken down by the years 2019-2024. Dynamic indicators (previous year = 100) were used, analyzing both the direction and intensity of changes. An assessment was carried out of the share of individual categories of own revenues, in particular the CIT tax, in the budgets of municipalities with county rights cities and municipalities without county rights cities. The structure and dynamics of revenues in the two types of local government units were compared. These methods allow for: the identification of trends over time, proper comparison of local government units, and determination of the impact of external factors (pandemic crisis, inflation, changes in PIT/CIT), and an objective assessment of the role of the CIT tax as a source of municipal revenue.

5. Analysis of Corporate Income Tax in Municipal Revenues in 2019-2024

Research on the role of the CIT tax in local finances indicates the need to analyze both the structure of local government own-source revenues and the macroeconomic conditions affecting the formation of tax revenues (Krajewska, 2012; Kosikowski, Ruśkowski, 2008). Taking these findings into account, this study employed the method of structural analysis and comparative analysis, which allow for the assessment of the relationship between the level of economic development of local government units and the amount of CIT revenue. Including data on legislative changes and macroeconomic trends made it possible to consider the context which – as the literature indicates – is essential for the proper interpretation of tax revenue formation.

Municipalities perform a wide range of public tasks. Consequently, imposing on municipalities the obligation to meet the needs of the community requires equipping these units with sufficient revenue. Figure 1 illustrates the development of municipal revenues, including cities with county rights, in the years 2019-2024. The period under analysis encompasses both the pre-COVID-19 pandemic phase and the period during the pandemic. Additionally, during the examined period, the outbreak of the armed conflict in Ukraine occurred. Throughout this period, the Polish economy also struggled with high inflation.

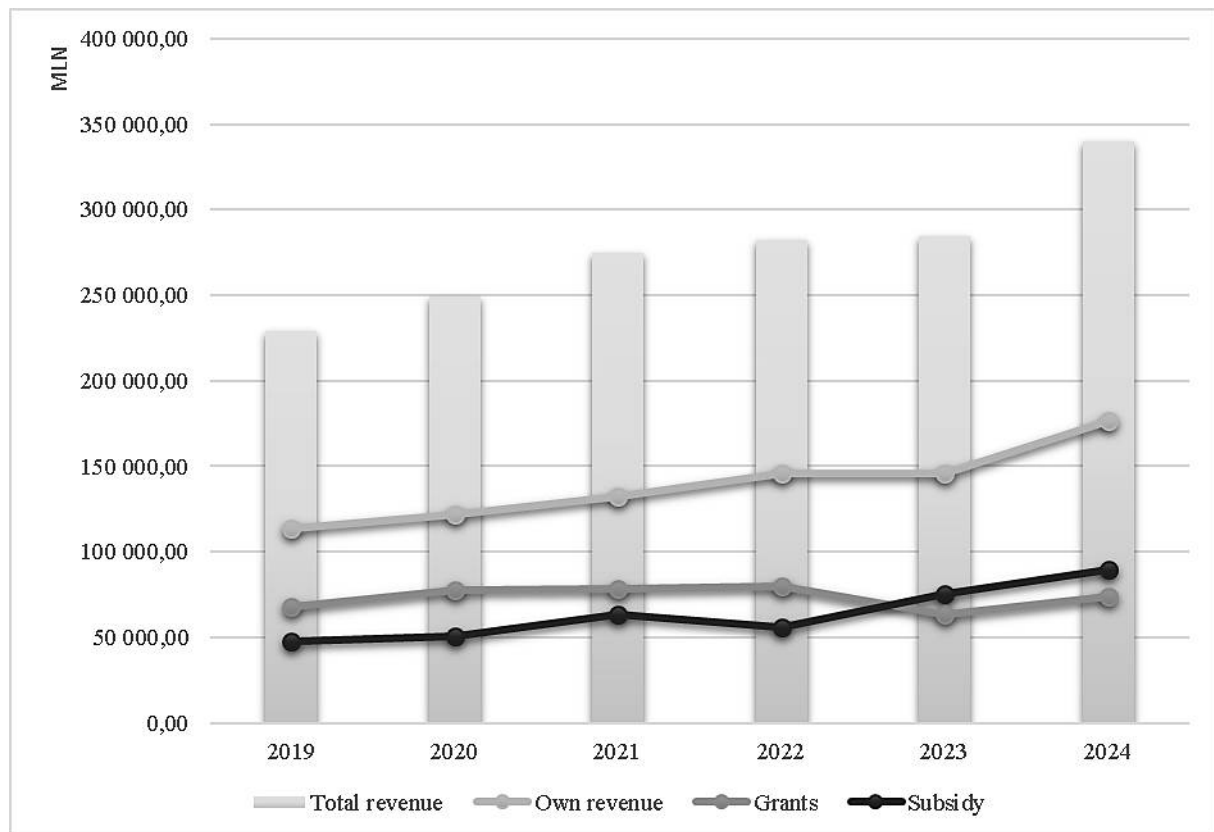


Figure 1. Municipal Revenues, including Cities with County Rights, by Category in 2019-2024 (in PLN million).

Source: own elaboration based on BDL data.

Total revenues of municipalities, including cities with county rights, in the years 2019-2024 exhibited an upward trend, which should be regarded as a positive phenomenon. Regarding own-source revenues, although an increase was observed, growth in 2023 compared to 2022 was slower. In the case of grants, an increase is visible in the years 2019-2022; only in 2023, compared to 2022, a significant decrease is evident. In terms of subsidies, a decline was noted only in 2022 compared to 2021. In 2024, a considerable improvement is visible in the revenues obtained by the basic units of local government, namely municipalities.

Table 1.

Dynamics of Municipal Revenues, including Cities with County Rights, in 2020-2024 (% , previous year = 100)

Specification	2020	2021	2022	2023	2024
Own revenue	107,18	108,61	110,31	100,21	120,92
Grants	113,73	101,77	101,83	78,67	116,98
Subsidy	106,03	126,34	88,08	134,53	118,83
Total revenue	108,88	110,07	102,72	100,92	119,49

Source: own elaboration based on BDL data.

Analyzing the dynamics of own-source revenues, it should be noted that their growth in 2023 compared to 2022 was minimal (0.21 percentage points). This situation resulted from changes in the personal income tax (PIT), which constitutes the main source of revenue for local government units (LGUs), including municipalities and cities with county rights. The changes in personal income tax included the introduction of a zero PIT for young people, an increase in the tax-free allowance, raising the tax threshold, and reducing the basic PIT rate from 17% to 12%. Despite compensatory payments made by the Polish government, they proved insufficient in the face of continuously rising budgetary expenditures of municipalities and cities with county rights. Regarding grants, a significant decrease (21.33 percentage points) was observed in 2023 compared to 2022 throughout the analyzed period. The decline in own-source revenues, combined with an increase in current expenditures, resulted in a considerable reduction in the capacity of local governments to implement investments. As for subsidies, a decline was noted in 2022 compared to 2021 (by 11.92 percentage points). A substantial improvement in the budgets of municipalities and cities with county rights was observed in 2024 compared to 2023. The diversification of revenue structures is of great importance for the overall financial system of municipalities and cities with county rights.

Table 2.

Structure of Own-Source Revenues of Municipalities and Cities with County Rights in 2019-2024 (in %)

Specification	2019	2020	2021	2022	2023	2004
Agricultural tax	1,35	1,33	1,25	1,16	1,34	1,27
Forest tax	0,26	0,25	0,23	0,23	0,34	0,29
Property tax	20,52	19,90	19,76	19,24	21,39	19,77
Tax on means of transport	1,03	0,96	0,94	0,90	0,97	0,85
Inheritance and gift tax	0,29	0,25	0,32	0,37	0,40	0,34
Tax on civil law transactions	2,58	2,47	3,39	2,85	2,72	2,32
Business tax of natural persons, paid in the form of a tax card	0,06	0,05	0,14	0,13	0,13	0,11
Shares in taxes constituting state budget revenues - personal income tax	42,35	38,74	40,22	39,30	30,33	39,13
Shares in taxes constituting state budget revenues - corporate income tax	3,22	3,12	3,57	3,47	4,97	5,24
Stamp duty revenues	0,44	0,40	0,44	0,42	0,43	0,37
Revenues from the service charge	0,35	0,31	0,29	0,29	0,28	0,25
Revenues from the market fee	0,12	0,09	0,00	0,08	0,08	0,07
Revenues from other local fees collected by local government units on the basis of separate acts	5,82	7,30	7,94	8,24	9,04	7,59
Other income - receipts from services	5,20	4,00	4,23	4,86	5,66	5,49
Income from assets	6,22	6,09	7,11	6,54	6,58	5,49
Other income - funds for co-financing own tasks obtained from other sources	0,74	6,45	1,32	1,29	3,66	2,63

Source: own elaboration based on BDL data.

In the structure of own-source revenues of municipalities and cities with county rights throughout the analyzed period, two significant sources funding the budgets of these local government units should be highlighted: the share in personal income tax (PIT) and the property tax. The lowest share of personal income tax in municipalities' own-source revenues was recorded in 2023 (30.33%), while the highest share occurred in 2019 (42.35%). The share of property tax in the own-source revenues of municipalities and cities with county rights averaged nearly 20% during the analyzed period. With regard to corporate income tax (CIT), it should be noted that its share in own-source revenues decreased in 2020 compared to 2019, which corresponded to the onset of the COVID-19 pandemic. The highest share of CIT in total revenues was observed in 2024 (i.e., 5.24%). The significance of CIT in municipal budgets should be considered not only in fiscal terms but also as an indicator of economic development and investment attractiveness of a given area. Municipalities that effectively support local businesses and attract investors can expect higher CIT revenues, thereby strengthening their financial independence and development potential.

The above information regarding finances pertains to municipalities along with cities with county rights. However, it is also important to present the development of individual revenue sources separately for cities with county rights and municipalities without county rights.

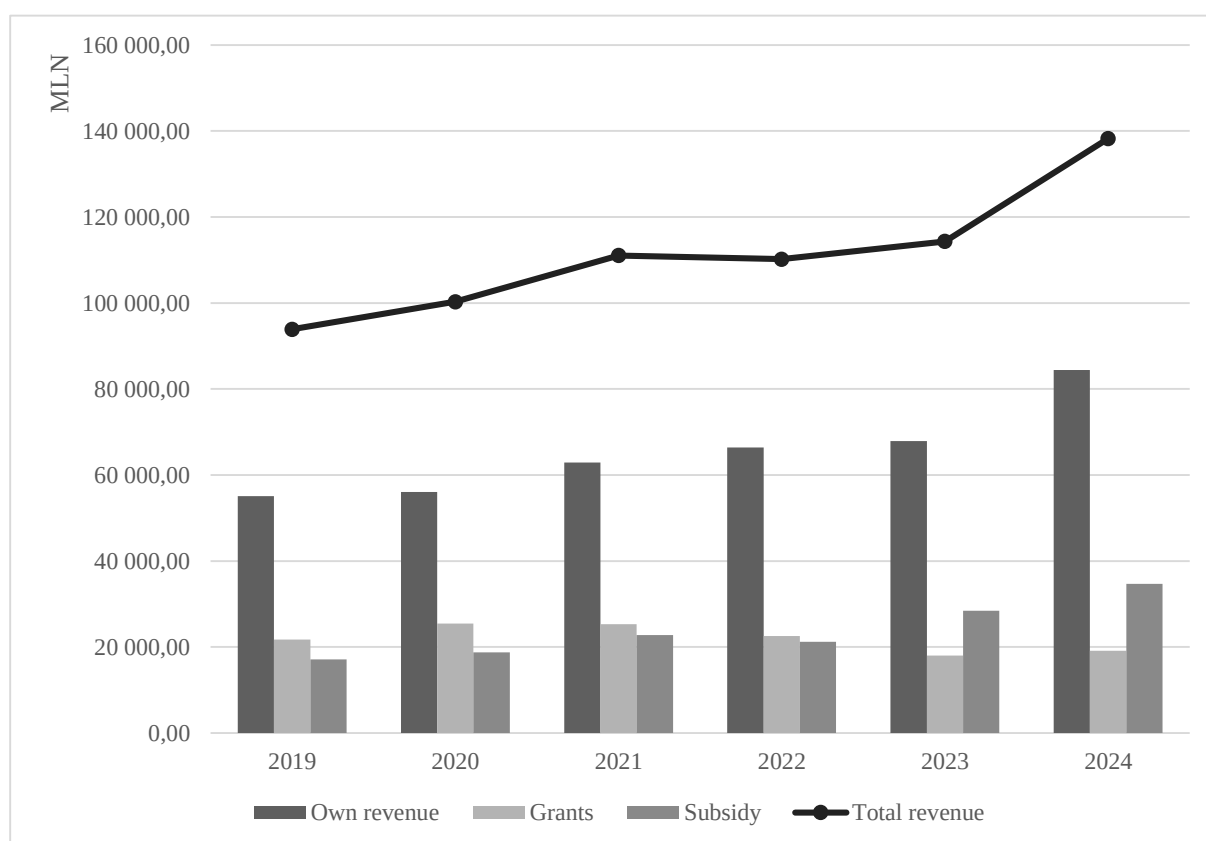


Figure 2. Revenues of Cities with County Rights by Category in 2019-2024 (in PLN million).

Source: own elaboration based on BDL data.

Total revenues of cities with county rights in the years 2019-2023 exhibited an upward trend. Total revenues amounted to PLN 93,894.37 million in 2019 and increased to PLN 114,341.97 million in 2023. Regarding own-source revenues, an increase was observed throughout the analyzed period. In the case of grants, a downward trend was noted in the years 2021-2023. As for subsidies, a decline was observed only in 2022 compared to 2021.

Table 3.

Dynamics of Revenues of Cities with County Rights in 2020–2024 (% , previous year = 100)

Specification	2020	2021	2022	2023	2024
Own revenue	101,84	112,25	105,56	102,20	124,28
Grants	117,19	99,47	89,14	79,89	106,07
Subsidy	109,78	121,28	92,99	134,08	122,19
Total revenue	106,84	110,70	99,24	103,76	120,89

Source: own elaboration based on BDL data.

Table 3 presents the dynamics of budgetary revenues of cities with county rights. Based on the above results, it should be noted that own-source revenues experienced growth. The upward trend in 2023 compared to 2022 was slight (2.20 percentage points). This situation resulted from changes in the personal income tax (PIT). The highest increase occurred in 2021 compared to 2020 (an increase of 12.25 percentage points). Regarding grants, a significant decline was observed throughout the analyzed period, beginning in 2021 and continuing through 2023. In terms of subsidies, a decrease was noted in 2022 compared to 2021 (by 7.01 percentage points). Based on the conducted analysis of revenue dynamics, a significant increase in own-source revenues, subsidies, and grants is evident in 2024, which should be regarded as a positive phenomenon. This growth resulted from several key factors, which can be grouped into three areas: legislative and systemic changes, improvement of the revenue base and economic conditions, and increased transfer support from the state. In 2024, a new Act on the Revenues of Local Government Units was adopted (effective from 2025, although preparations and provisions were already applicable in 2024), which, among other things, modified the rules for calculating LGUs' shares in taxes (PIT/CIT) and mechanisms for equalization subsidies. In particular, higher participation rates in personal and corporate income taxes were provided for cities with county rights – the proposed rates for these cities were 8.6% in PIT and 2.2% in CIT. Equalization mechanisms (the “balancing” components) in the general subsidy were significantly increased in 2024. It should be noted that a portion of the revenue growth for cities with county rights resulted from increased statutory (systemic) shares and transfers, not solely from a purely economic increase in the tax base.

Table 4.*Structure of Own-Source Revenues of Cities with County Rights in 2019-2024 (in %)*

Specification	2019	2020	2021	2022	2023	2024
Agricultural tax	0,04	0,04	0,04	0,04	0,04	0,04
Forest tax	0,01	0,01	0,01	0,01	0,01	0,01
Property tax	16,39	16,45	15,87	15,97	17,39	15,61
Tax on means of transport	0,64	0,62	0,55	0,55	0,57	0,48
Inheritance and gift tax	0,33	0,31	0,37	0,44	0,49	0,40
Tax on civil law transactions	2,91	2,84	3,91	3,32	3,29	2,46
Business tax of natural persons, paid in the form of a tax card	0,05	0,05	0,15	0,15	0,13	0,11
Shares in taxes constituting state budget revenues - personal income tax	45,15	43,09	43,33	40,87	33,36	42,25
Shares in taxes constituting state budget revenues - corporate income tax	4,75	4,65	4,95	5,33	7,34	7,58
Stamp duty revenues	0,59	0,56	0,59	0,63	0,65	0,55
Revenues from the service charge	0,02	0,02	0,01	0,01	0,01	0,01
Revenues from the market fee	0,04	0,03	0,00	0,02	0,02	0,02
Revenues from other local fees collected by local government units on the basis of separate acts	5,36	6,82	7,18	7,85	8,62	7,14
Other income - receipts from services	7,31	5,63	5,71	6,74	7,67	6,68
Income from assets	7,09	7,24	8,10	7,55	7,81	6,33
Other income - funds for co-financing own tasks obtained from other sources	0,30	3,66	0,50	1,05	2,20	1,22

Source: own elaboration based on BDL data.

In the structure of own-source revenues of cities with county rights throughout the analyzed period, two main sources of budgetary revenues should be highlighted: the share in personal income tax (PIT) and property tax. The lowest share of personal income tax in municipalities' own-source revenues was recorded in 2023 (33.36%), while the highest share occurred in 2019 (45.15%). The share of property tax in the own-source revenues of cities with county rights averaged 16% during the analyzed period. Regarding corporate income tax (CIT), the lowest share in own-source revenues occurred in 2020 (4.65%), while the highest was recorded in 2024 (7.58%). It can be observed that during the analyzed period, the share of municipal revenues from CIT in own-source revenues increased, which should be regarded positively. The lowest shares of own-source revenues in terms of tax revenues were recorded for agricultural tax, forest tax, and business tax paid by individuals in the form of a tax card.

It is also important to present the development of revenues in municipalities without cities with county rights.

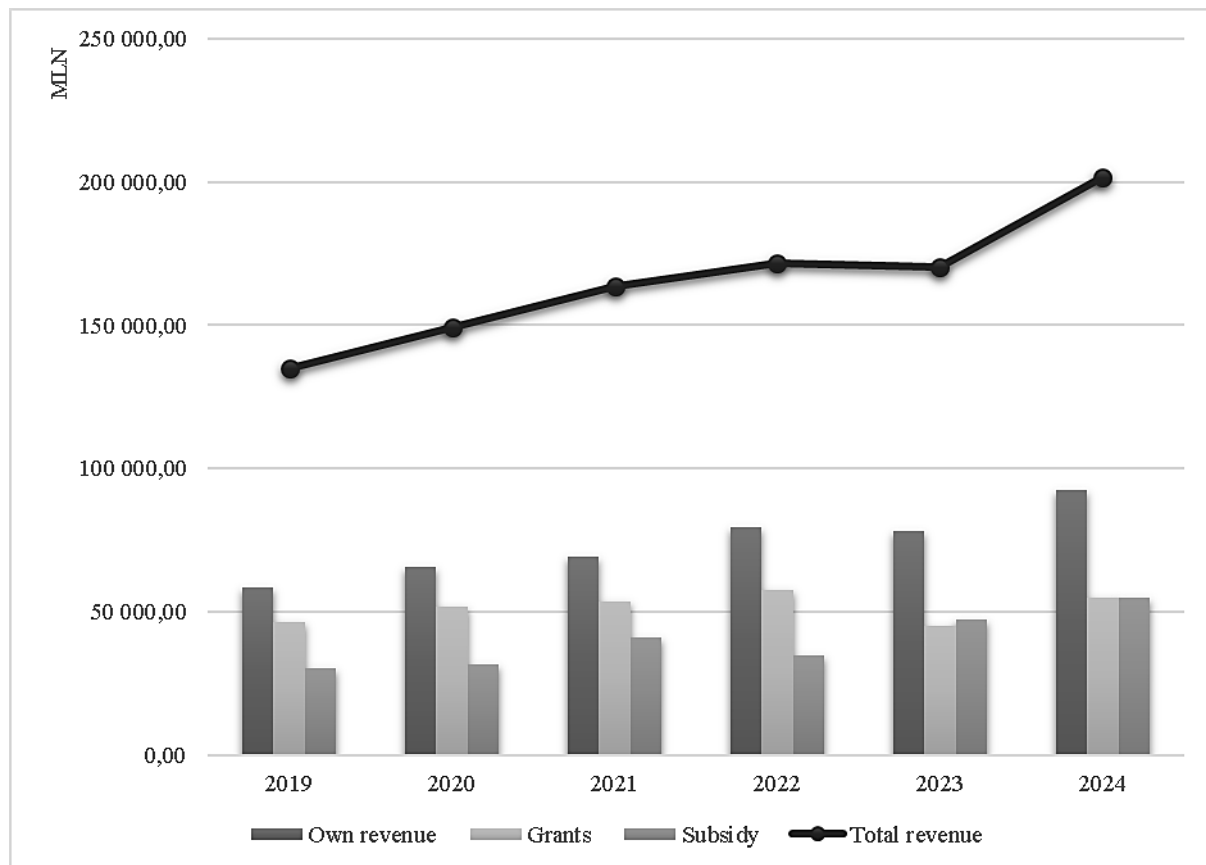


Figure 3. Revenues of Municipalities without Cities with County Rights by Category in 2019-2024 (in PLN million).

Source: own elaboration based on BDL data.

Total revenues of municipalities without cities with county rights in the years 2019-2022 exhibited an upward trend. Only in 2023, compared to 2022, was a decline observed. Regarding own-source revenues, an increase was recorded in 2019-2022, while a decrease was noted in 2023 compared to 2022. Grants exhibited an upward trend in 2021-2023. As for subsidies, a decline was observed in 2022 compared to 2021, which was characteristic for all local government units. In 2024, an improvement in the financial situation of municipalities without cities with county rights should be noted in comparison to 2023.

Table 5.

Dynamics of Revenues of Municipalities without Cities with County Rights in 2020-2024 (% , previous year = 100)

Specification	2020	2021	2022	2023	2024
Own revenue	112,20	105,51	114,63	98,54	118,00
Grants	112,11	102,89	107,86	78,20	121,34
Subsidy	103,92	129,36	85,35	134,81	116,80
Total revenue	110,31	109,65	105,10	99,09	118,55

Source: own elaboration based on BDL data.

Table 5 presents the dynamics of budgetary revenues of municipalities without cities with county rights. Based on the above results, it should be noted that own-source revenues increased during the years 2020-2022. In 2023, compared to 2022, a decrease of 1.46 percentage points

was recorded. The highest increase occurred in 2022 compared to 2021 (an increase of 14.63 percentage points). Regarding grants, an increase in budgetary revenues from this source was observed in 2020-2022. Only in 2023, compared to 2022, was a decline recorded (21.80 percentage points). When comparing grant revenues to cities with county rights, a significant decrease was observed throughout the analyzed period, particularly from 2021 to 2023. In terms of subsidies, during the entire analyzed period, a decline was observed only in 2023 compared to 2022 (0.91 percentage points).

Table 6.

Structure of Own-Source Revenues of Municipalities without Cities with County Rights in 2019-2024 (in %)

Specification	2019	2020	2021	2022	2023	2024
Agricultural tax	2,59	2,43	2,35	2,10	2,47	2,38
Forest tax	0,50	0,45	0,44	0,41	0,63	0,54
Property tax	24,41	22,84	23,29	21,99	24,86	23,58
Tax on means of transport	1,40	1,25	1,29	1,20	1,32	1,19
Inheritance and gift tax	0,25	0,20	0,27	0,31	0,33	0,29
Tax on civil law transactions	2,26	2,15	2,92	2,45	2,23	2,20
Business tax of natural persons, paid in the form of a tax card	0,06	0,05	0,13	0,13	0,12	0,11
Shares in taxes constituting state budget revenues - personal income tax	39,71	35,02	37,39	37,98	27,69	36,27
Shares in taxes constituting state budget revenues - corporate income tax	1,77	1,81	2,32	1,91	2,91	3,10
Stamp duty revenues	0,31	0,26	0,30	0,24	0,24	0,21
Revenues from the service charge	0,66	0,56	0,55	0,51	0,51	0,46
Revenues from the market fee	0,20	0,15	0,00	0,13	0,14	0,12
Revenues from other local fees collected by local government units on the basis of separate acts	6,25	7,70	8,64	8,57	9,40	8,01
Other income - receipts from services	3,22	2,61	2,88	3,29	3,91	3,73
Income from assets	5,40	5,11	6,20	5,69	5,51	4,73
Other income - funds for co-financing own tasks obtained from other sources	1,15	8,84	2,06	1,49	4,92	3,79

Source: own elaboration based on BDL data.

In the structure of own-source revenues of municipalities without cities with county rights throughout the analyzed period, two main sources of budgetary revenues should be highlighted: the share in personal income tax (PIT) and property tax. The lowest share of personal income tax in the own-source revenues of municipalities was recorded in 2023 (39.71%), while the highest share occurred in 2019 (45.15%). The highest share of property tax in own-source revenues of municipalities without cities with county rights reached 24.86%, while the lowest was recorded in 2022 (21.99%). Regarding corporate income tax (CIT), the highest share occurred in 2024 (3.10%). The lowest shares of own-source revenues in terms of tax revenues were observed for inheritance and donation tax, vehicle tax, forest tax, and business tax paid by individuals in the form of a tax card.

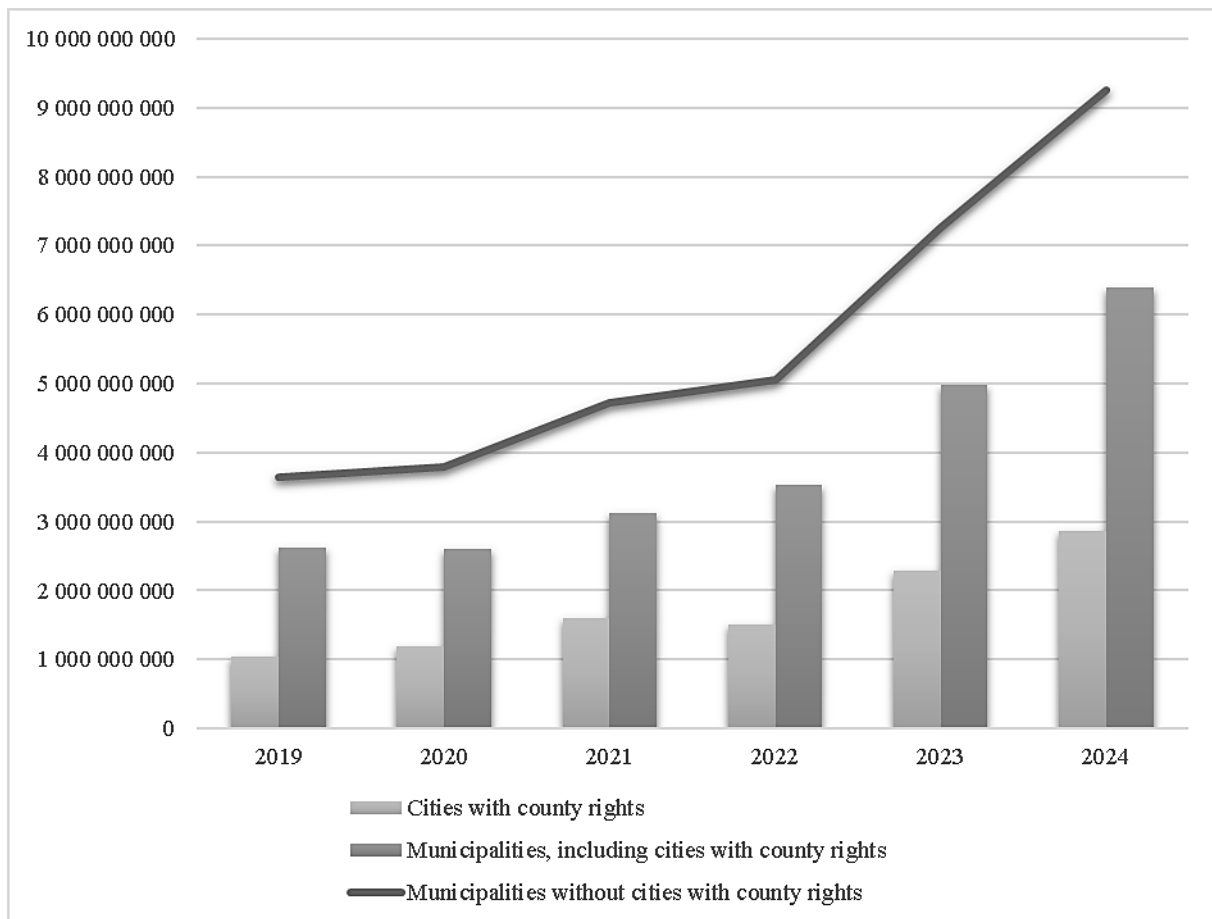


Figure 4. Municipal revenues from participation in taxes constituting state budget revenues - corporate income tax by category in the years 2019-2024 (in million PLN).

Source: own study based on BDL data.

In all three categories of local government units analyzed, a very strong increase in CIT revenues is visible in the years 2019-2024. The growth rate accelerates particularly after 2022. Revenues grow the most in the case of cities with county rights — an especially intense increase after 2022. This may reflect improved corporate profitability, the relocation of tax centers to larger municipalities, legislative changes (e.g., the impact of the Polish Deal in the first years and the subsequent rebound in revenues), and a higher share of companies paying CIT in these units. In the years 2019-2021, a stable, moderate growth is visible, partially restrained by the pandemic. In the years 2021-2022, CIT revenues are increasing in all the analyzed municipalities, but the dynamics vary: overall municipalities +7%, municipalities without county-level cities: decrease -5.7%, cities with county rights +13%. The years 2022-2024 are the most important period — rapid CIT growth, even by several dozen percent annually. This may result from the economic rebound after pandemic slowdowns, increased profitability of companies, the effects of tax changes (e.g., limiting deductions, simplifications or changes in CIT settlements), and nominal revenue growth of companies amid high inflation. The data suggest that the CIT system has become more favorable for local governments in recent years, particularly for large cities and municipalities with a stable corporate base.

The autonomy of municipalities in the expenditure of CIT revenue, emphasized in the literature, is also evident in the actual functioning of local government units. Individual municipalities, depending on local needs and development priorities, allocate funds obtained from CIT to different categories of public tasks. For example:

1. Gdańsk (a city with county rights) For several years, Gdańsk has allocated a significant portion of its own revenue — including CIT income — to the expansion of transport and communication infrastructure, including the modernization of the road network and investments in public transport. The city's budget has repeatedly emphasized that the increase in CIT results from a strong service sector and IT industry, which directly supports local infrastructure investments (<https://bip.gdansk.pl/urzad-miejski/Sprawozdanie-z-wykonania-budzetu-Miasta-Gdanska-za-2024-r,a,284155>).
2. Kleszczów (a rural municipality with the highest income in Poland). In the Kleszczów municipality, which benefits from revenues from industrial activities (including the energy sector), own funds — including the share of corporate income tax (CIT) — have enabled the financing of local educational scholarship programs, subsidies for residents, and the expansion of sports infrastructure. This example shows that a high share of CIT in own revenues directly translates into an expansion of public services (<https://www.bip.kleszczow.pl/>).
3. Rzeszów – the city allocates a portion of its CIT income to the development of the economic zone and innovation support programs. Higher tax revenues from the manufacturing and service sectors have allowed the financing of projects that attract investors (including improving the technical standards of investment areas) (<https://bip.erzeszow.pl/361-finanse-miasta-rzeszowa/12892-sprawozdania-rb-z-za-2024-r.html>).
4. Niepołomice – the commune, known for its active policy of attracting investors, uses revenue from corporate income tax (CIT) to develop industrial zones, which in turn generates additional tax income. CIT revenue is an important source of funding for technical infrastructure here, including access roads and water and sewage networks (<https://www.niepolomice.eu/informator-categories/budzet-i-finanse/>).

5. Results

In the analyzed period of 2019-2024, both municipalities and cities with county rights recorded an overall increase in revenues, although the dynamics varied. In 2023, there was a slowdown in the growth of own revenues, particularly visible in municipalities without cities with county rights. In 2020-2021, most revenue categories exhibited growth, except for certain grants and subsidies, which in some years showed declines. Throughout the entire observation

period, the share of CIT in municipalities' own revenues increased. The highest share of CIT in the structure of own revenues was observed in 2024 in both cities with county rights and municipalities without such cities. The increase in the share of CIT coincided with the improvement in business financial results and legislative changes concerning the local government revenue system.

6. Discussion

The research results indicate that corporate income tax (CIT) plays an increasing role in municipal budgets in Poland, which is consistent with trends reported in the literature. As Krajewska (2012) emphasizes, income taxes are a key element of modern financial systems, and their importance grows with the development of entrepreneurship and economic integration. The obtained results confirm this pattern: the increase in CIT revenues in 2024 aligns with the improvement of the economic climate and the recovery of business activity after the COVID-19 pandemic. Previous studies (Kosikowski, Ruśkowski, 2008; Krajewska, 2012) also indicate that the share of CIT in local government revenues is strongly correlated with the level of regional economic development. The results of the present study confirm this relationship: cities with county rights, which have a larger business base, achieve significantly higher CIT revenues than rural municipalities.

The novelty of this research lies in the combination of CIT revenues with the context of legislative changes, particularly reforms concerning PIT and the share of local government units (LGUs) in the state budget revenues. The observed fluctuations in municipal revenues in 2023 result, among other things, from the reduction of PIT for individuals, which decreased LGUs' share in this tax, making CIT revenue relatively more significant.

The results confirm the hypothesis of the growing importance of CIT, although the share of this tax still remains smaller than the share of PIT and property tax. The observed differences between groups of municipalities also confirm the hypothesis of CIT being more significant in urban and metropolitan units. Further research should include an analysis of the impact of tax reliefs, exemptions, and changes in CIT rates on municipal budgets, as well as an assessment of the long-term effects of the planned reform of LGUs' shares in state taxes.

7. Summary

According to the legislator's intent, the primary source of municipal revenues was to be, first and foremost, own-source revenues. However, differences in the level of own-source revenues proved to be significant, such that in some municipalities, their level is so low that it would practically prevent the execution of public tasks imposed on these local government units. Addressing these disparities in municipal budget revenues is achieved through financial transfers from the state budget to municipal budgets. The financial system in Poland distinguishes between revenues classified as own-source and external, transferred from the state budget. Municipalities thus have at their disposal local taxes, shares in taxes constituting state budget revenues, as well as earmarked grants and general subsidies. Own-source revenues are crucial for municipalities, as they simultaneously indicate their financial independence. However, the level of own-source revenues generated by municipalities appears insufficient to fully guarantee the proper execution of public tasks at the highest standard. It should also be noted that a fundamental objective of reforms in the financing system of local government units after 2003 was to increase their own-source revenues, which was primarily achieved through the increase of the aforementioned percentage shares in taxes constituting state budget revenues, including corporate income tax (CIT). Nevertheless, the percentage shares in CIT are dependent on the economic cycle. Corporate income tax (CIT) constitutes an important source of municipal revenues in Poland, closely linked to the condition of the local economy. Although its share in the structure of local government revenues is smaller than that of personal income tax (PIT) or general subsidies, it is crucial for municipalities with a well-developed business sector. In such units, CIT can provide a significant boost to the budget, enabling the financing of investments, infrastructure improvement, and the development of public services. In recent years, an increase in CIT revenues to municipal budgets has been observed, particularly evident in 2024 compared to 2023. This growth results both from improved financial performance of firms and the maintenance of favorable principles for the allocation of revenues between the state budget and local governments. The increase demonstrates that the development of local entrepreneurship directly translates into municipalities' financial capabilities and their capacity to perform public tasks. In conclusion, corporate income tax plays an increasingly important role in financing local government tasks and constitutes a vital element of local economic policy. Its stable growth is not only beneficial for municipal budgets but also confirms that entrepreneurship development forms the foundation for sustainable local development in Poland.

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ECONOMIC IMPORTANCE OF THE CULTURAL SECTOR IN POLAND

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Purpose: Cultural operators contribute significantly to economic and financial performance and stimulate innovation in other sectors. The aim of this study is to determine the importance of the cultural sector in the economy. The Polish cultural sector was assessed in the context of the performance of other EU countries.

Design/methodology/approach: The focus was on the quantitative approach to the issue discussed here. Therefore, in order to achieve the aim in question, relevant literature and secondary Eurostat data on culture and selected aspects of the economy were analysed.

Findings: The results obtained show that Poland ranks below average compared to other EU countries, taking into account metrics such as the share of people employed in the cultural sector in total employment, the share of enterprises in this sector in total enterprises, the share of value added generated by the cultural sector in industry, construction, and market services, as well as value added per capita. On the positive side, the balance of trade in cultural goods was positive. Such results suggest that the potential of the cultural sector in Poland is underutilised.

Practical implications: It is necessary to make full use of the potential of the people employed in cultural sector, especially their knowledge and creative skills. To this end, however, it is necessary to create legal conditions regulating the employment of these employees to a greater extent, as well as economic conditions fostering cooperation between culture and business. An economy based on culture will enable the production of more complex and innovative technologies and goods.

Originality/value: The article provides current evidence on the state of the cultural sector in Poland, taking into account its economic aspect. The sector's situation is presented in comparison to other European Union countries.

Keywords: cultural sector, cultural goods, economy.

Category of the paper: Research paper.

1. Introduction

The changes taking place in modern societies and economies, especially the transition to a knowledge-based economy, globalisation, and the widespread use of new communications solutions, make intangible factors, particularly those generated by human capital, increasingly important in gaining competitive advantage for enterprises and countries (Mackiewicz, Michorowska, Śliwka, 2009). The role of industries based on knowledge, creativity, and innovation is increasing in the economy, including cultural industries (Krapiński, 2014). The creative and cultural industries play an important role in generating economic goods from creative activities, thus contributing to the economic and social development of countries, they are essential for territorial competitiveness (Ortiz-Ospino, González-Sarmiento, Roa-Perez, 2025). They are recognised as “dynamic economic sectors fostering cultural diversity, social cohesion and technological innovation” (Holy, Budak, Medić, 2025, p. 1). In consequence, the economic aspect of sectors offering cultural goods and content is increasingly emphasised. The cultural and creative sectors are among the most dynamic sectors. They generate annual revenues of nearly USD 2.3 trillion worldwide, which accounts for 3.1% of global gross domestic product and for an estimated 6.2% of global employment (United Nations, 2024). These data show the important role of the cultural sector in the economy.

The economic importance of culture has been highlighted in many international documents. The UNESCO Convention on the Protection and Promotion of the Diversity of Cultural Expressions (2005) emphasises that culture is one of the main driving forces behind the development of countries and that cultural activities, goods, and services have both economic and cultural importance. The economic role of culture is also emphasised in the strategic documents of the European Union, in which the cultural and creative sectors are seen as a source of innovative ideas that give rise to products and services driving economic growth and job creation. Moreover, these sectors contribute to the fight against all forms of discrimination, including racism and xenophobia, and are a platform for freedom of expression and for the promotion of respect for cultural and linguistic diversity (Regulation of the European Parliament, 2013).

Cultural operators contribute significantly to GDP and stimulate innovation in other sectors. They also play an important role in the formation of the information society, the implementation of investments in modern information and communications solutions and the development of e-skills, the stimulation of research, the provision of innovative products and services, and the promotion of social dialogue (European Commission, 2010). A stronger focus on the cultural sector's contribution to economic and financial performance is therefore necessary.

In the literature, there is a lack of up-to-date research on the economic significance of culture in Poland in comparison with other countries. The regional and national aspects have been examined, but without a comparative context—the conducted studies cover the period only up to 2020. This study addresses that gap.

The aim of this study is to determine the importance of the cultural sector in the economy. The significance was established based on changes taking place within the cultural sector, alongside an analysis of its current state, taking into account the economic dimension.

This paper addresses the following research questions:

RQ1: What is the situation of Poland in the analyzed scope compared to EU countries?

RQ2: What changes can be observed in this regard?

To achieve the objective, the method of literature analysis was applied. An analysis of Eurostat secondary data on culture and selected aspects of the economy was also conducted.

In the first part of this study, the concept and characteristics of the cultural sector are presented based on an analysis of the literature. In the empirical part, secondary Eurostat data were used. In order to assess the role of the cultural sector in the economy, an analysis of the cultural sector was conducted, taking into account the sector's impact on job creation and employment conditions, value-added generation, and commercial performance.

2. Literature review

2.1. The concept of cultural sector

The cultural field is defined taking into account artistic value, creativity, or copyright. It includes not only culture understood in the traditional way, but also activities within the cultural and creative industries in which cultural activities of a commercial nature are conducted. Cultural industries comprise enterprises producing and selling market-oriented and mass-produced cultural goods and services based on copyright, whereas entities operating within creative industries seek to create and sell goods and services that result from the consumption of cultural resources, require creative input, and carry cultural content (GUS, 2018).

In their research, authors frequently employ the concept of cultural sector used in various contexts. Understood broadly, it encompasses all cultural operators engaged in cultural activities for which these activities are the main purpose, such as public institutions (state and local government), private institutions, and non-profit organisations that, while established on private initiative, pursue public goals. Such an interpretation also includes artists and cultural managers or informal cultural initiatives (Krasucka, n.d.). A broad interpretation is also used by the European Union. The cultural and creative sectors are defined as all sectors whose

activities are based on cultural values or creative, artistic expressions, regardless of the nature of these activities (market-oriented or not), the type of structure, and the method of financing. The activities of operators in these sectors include the development, creation, production, dissemination and preservation of goods and services that embody cultural, artistic or other creative expressions, as well as related functions, such as education or management (Regulation of the European Parliament, 2013). In a narrow perspective, the focus is on that part of the cultural and creative sectors that produces consumer cultural goods and services, which are an end in themselves for related activities (Kosińska, 2020).

It should be emphasised that there is terminological ambiguity in the literature regarding the concepts of cultural sector and creative sector (as well as cultural industries and creative industries). They are either analysed together, or one is seen as part of the other (Kosińska, 2020). This study will focus on the broad interpretation of the cultural sector. This means that the cultural and creative sectors will be analysed together. The category referred to as related industries, which includes those economic activities that are dependent on cultural and creative industries, but are not based on artistic and cultural creativity, will not be included.

The interrelationships between the cultural and creative sectors are represented as concentric circles. A model developed by Throsby shows the economic interdependence between the cultural and creative sectors and other industries (Reid, Albert, Hopkins, 2010). Throsby emphasises that the value of cultural goods is transferred from the inner “core” outwards, to broader economic categories, which then commercialise these goods (Throsby, 2001), which shows the link between the cultural and creative sectors and other economic sectors. A model based on the division of the above sectors into individual areas was also developed by the KEA consultancy for the European Commission (Kea European Affairs, 2006) (Figure 1). The inner circle includes core arts, such as visual arts, performing arts, and cultural heritage. Arts that are non-industrial in nature are the foundation of the model, and the outputs are used by cultural industries, which includes sectors such as film and video, television and radio, video games, books and press, and music. These industries reproduce and distribute creative products on a mass scale, while at the same time affecting creative industries, shaped by design, architecture, and advertising (Pięta-Kanurska, 2013).

In the concentric circles model, effects diffuse from the inside to the outside. However, the links between the individual sectors can work both outwards and towards the inner circles, as well as within the same circle (Szultka, 2012), generating cultural, social and economic effects.

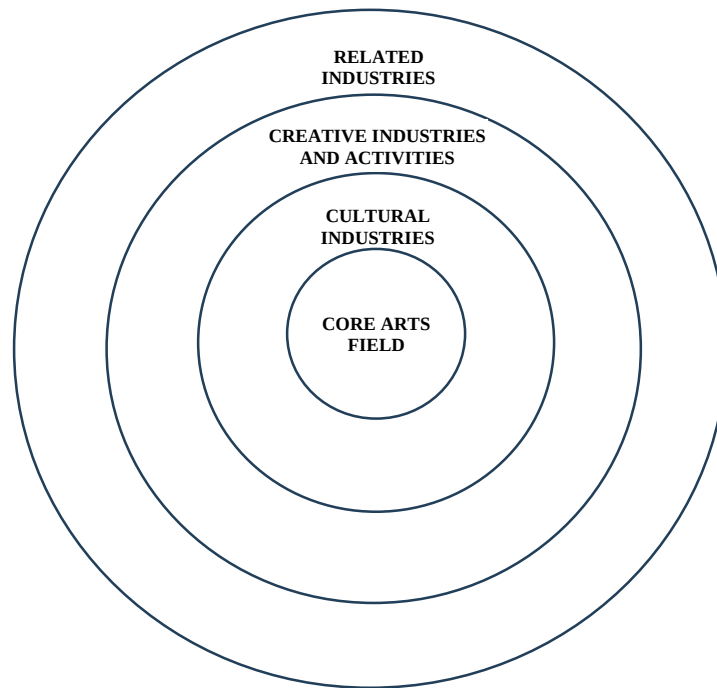


Figure 1. The concentric circles model of the cultural and creative sectors.

Source: Kea European Affairs, 2006.

2.2. The economic dimension of the cultural sector

Culture encompasses all material and spiritual wealth created by man over the course of history or in a specific period, accumulated, preserved, enriched over time, and passed on from generation to generation (Doroszewski, 2000). It has an impact on the economic and social aspects of the activities of individuals (Kutwa, 2022), as well as economic development. This impact is considered in three dimensions (Błaszczyk, Banaszak, 2020; cf. Mazurkiewicz, Szara, 2024):

- economic, which emphasises the economic effects relating to culture,
- the quality of life of individuals, as the consumption of cultural content is significant for the well-being of individuals for whom postmaterialist values are important,
- the foundations of social order, as the consumption of culture is a form of inclusion into social and public life.

This study will focus on culture as a factor driving economic development, influencing the behaviour of market participants, and supporting or initiating the production of specific products (Kasprzak, 2013). In the context presented, it is important to emphasise the institutional approach to culture, whereby it is interpreted as a “sector of the economy comprising various forms of cultural activities and their outputs (goods and services)” (GUS, 2018, p. 24).

Entities operating in this sector influence everyday life - they shape relations between cultures, thus creating new ways of perceiving society. Cultural goods and services, through their economic, cultural, and expressive value, enrich the lives of those who use them (Ortiz-

Ospino, González-Sarmiento, Roa-Perez, 2025). At the same time, research increasingly explores the impact of culture, focusing primarily on its economic implications. In this context, culture is recognized as a distinct sector of the economy, and its analysis is crucial for developing effective public and private strategies (Gandini, Olaskoaga-Larrauri, Usobiaga, Sopelana, 2025).

Thus, the status of the cultural sector as a strategic pillar of the national economy is gaining in importance (Deng, Chen, Jiang, 2025). There is growing recognition of the role of the cultural sector in driving territorial development and competitiveness (UNESCO, 2012), as well as the contribution of culture and creativity to global GDP (UNCTAD, 2024). Astikè (2022) identifies the impact of individual factors of the cultural sector on the competitiveness of EU countries, confirming that they contribute to increased competitiveness. Activities involving the production, promotion, and dissemination of cultural goods and services transform territories into smart spaces, also contributing to the improvement of residents' quality of life (Ortiz-Ospino, González-Sarmiento, Roa-Perez, 2025).

Studies presented in the literature confirm a positive relationship between the cultural sector and the economic growth of regions (Liang, Wang, 2020; Zhou, Siriboonchitta, Yamaka, Maneejuk, 2020). At the same time, the growing economic significance of culture raises the question of how to harness the potential of the cultural sector, considering both supply and demand factors.

On the other hand, entities operating in Poland's cultural sector are primarily micro-enterprises, which employ the majority of workers in this sector (Kutwa, 2022). Since enterprise size is positively correlated with innovation capacity (Arora et al., 2022), this suggests a limited impact of the cultural sector on socio-economic development in Poland. This observation highlights the need for empirical research focused on the economic dimension of the cultural sector.

3. Methods

To evaluate empirically the theoretical observations reported in the literature, secondary Eurostat data on cultural sector and selected aspects of the economy were also analysed in EU Member States.

Although national statistics collect information on the economic aspect of culture, the concept and definitions of the cultural sector are diverse and reflect the cultural diversity of individual countries. This is manifested in different statistical methodologies and classifications used. Comparing sectors between countries - and thus the outcomes of research - requires adopting a specific conceptualization of the broadly understood cultural sector.

In this study, the following indicators reflecting the economic dimension of the cultural sector were considered (Kutwa, 2022):

- cultural employment: number of employees; share of people employed in the cultural sector in total employment; educational attainment of cultural workers; form of employment,
- activities of cultural enterprises: number of cultural enterprises; share in total industry, construction, and market services,
- value added generated by cultural enterprises: value added; share in total industry, construction, and market services; value added per employee,
- trade in cultural goods: exports; imports; trade balance; share of cultural trade in total exports; share of cultural trade in total imports,
- percentage of people working in the cultural sector in EU countries vs. GDP per capita.

The analysis of status focused on 2023 (where data for this year were unavailable, reference was made to 2022), while the analysis of changes covered the period 2014-2023.

Knowledge of the cultural sector in terms of indicators can provide a significant argument for its importance to social and economic development.

3. The research results

3.1. Analysis of employment in the cultural sector

7.8 million people were employed in the cultural sector in the EU in 2023, which accounted for 3.8% of total employment. The lowest share of people employed in this sector was recorded in Romania (1.5%), while the largest was in the Netherlands (5.3%) (Figure 2). Overall, this share was higher in the northern and western EU countries (with the exception of Spain) than in the southern and eastern countries. In Poland, 622,300 people were employed in this sector, which accounted for 3.6% of total employment, putting the country below the EU average.

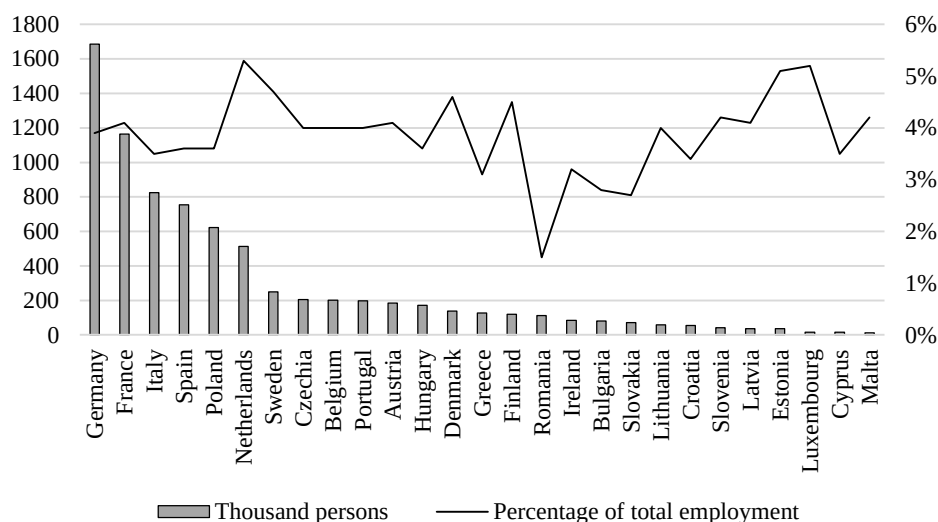


Figure 2. Cultural employment in EU countries, 2023.

Source: Own elaboration based on Eurostat data.

The analysis of employment by basic socio-demographic characteristics (especially by gender and age) does not show any significant differences between the cultural sector and total employment. The differentiating factor is the level of education – it is primarily people with higher education who find employment in the cultural sector, accounting for 61.8% of all cultural workers in 2023 (which far exceeds the total employment figure, i.e. 37.8%). The employment structure is also described by the form of employment. The cultural sector is characterised by a high share of self-employed workers. Almost one-third (31.7%) of cultural workers across the EU were self-employed (compared to 13.8% in the whole economy). It should be noted that there is great variation between the EU countries in this regard – in Italy and the Netherlands, self-employment accounted for nearly half of all employment in the cultural sector (46.6% and 45.7% respectively), while in Bulgaria, Luxembourg and Romania, it was less than 20%. At the same time, this sector is characterised by a lower percentage of full-time employees (75.8%, i.e. 5.4 p.p. less than in the whole economy). As with flexible employment, there is also great variation in full-time employment (ranging from 58.9% in the Netherlands to 95.6% in Bulgaria and 97.6% in Romania). While there are also differences in terms of employment stability, they are less pronounced. Employment in the cultural sector is characterised by lower stability than in the whole economy (81.8% vs. 86.5%), ranging from 68.5% in the Netherlands to 99.5% in Romania (Eurostat, 2024a).

At the same time, it should be noted that there have been significant changes in employment in the cultural sector over the last decade. Between 2014 and 2023, the number of people employed in the Member States, with the exception of Romania, Croatia and Slovenia, increased. In spite of this, the share of employees in this sector in total employment decreased in a third of the Member States. This trend also applies to countries with a high increase in the number of people employed, such as Malta (47.1%), the Netherlands (35.2%), Spain (27.2%),

and Estonia (25.0%). Such a change may imply that the cultural sector plays a smaller role in the economy than other industries, despite a growing interest in employment in it.

3.2. Activities of cultural enterprises

In 2022, there were 2.0 million of cultural operators in the EU, which accounted for 6.3% share of total in industry, construction, and market services. The largest number of enterprises were active in France (355,300), followed by Italy (253,600) and the Netherlands (243,000), with the least enterprises active in Luxembourg (2600) (Figure 3). The share of these operators in the total number of operators in industry, construction, and market services was highest in the Netherlands (11.0%) and Sweden (10.8%), and lowest in Bulgaria and Slovakia, standing at 3.1% in each. In Poland, even though there were 115,700 registered enterprises operating in the cultural sector, their share in the total number of enterprises was only 4.3%, with the country ranking third from bottom.

The analysis of the structure of cultural enterprises' activities shows that enterprises in the EU focus primarily on publishing activities (27.4% of cultural enterprises), whereas in Poland, they focus primarily on architectural activities (19.8%). Apart from publishing, which was the fourth most common activity in Poland, there are no significant differences between Poland and the other EU countries in terms of how the individual activities were ranked.

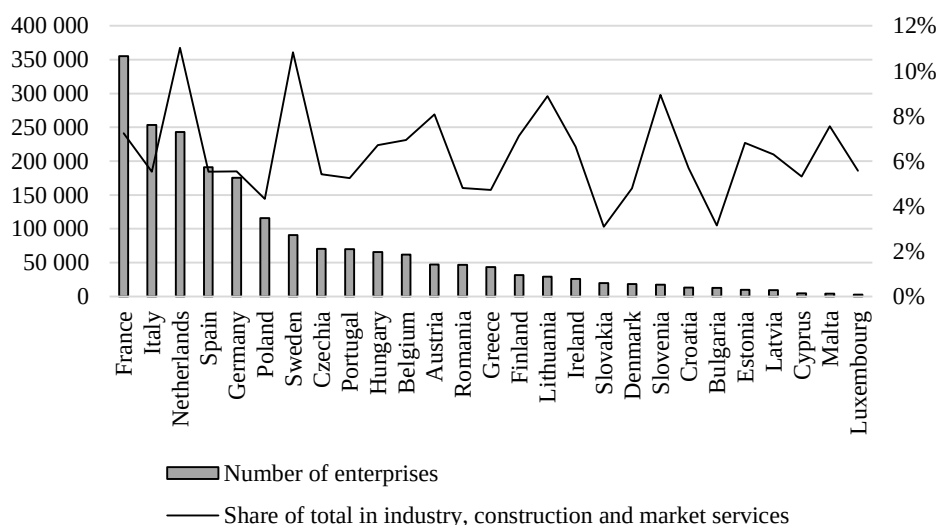


Figure 3. Cultural enterprises in EU Member States, 2022.

Source: Own elaboration based on Eurostat data.

3.3. Value added generated by cultural enterprises

In 2022, cultural operators generated EUR 198.52 billion in value added, an increase of 18.5 billion compared to 2021. Germany generated the highest value added (EUR 52.5 billion), followed by France (EUR 34.6 billion) and Italy (EUR 22.8 billion) (Figure 4). On average in the EU, the share of generated value added in industry, construction, and market services was 2%, ranging from 1% (in Slovakia) and 1.1% (in Luxembourg) to 5.4%

in Cyprus. The figure for Poland was EUR 6.3 billion, which accounts for 1.7% of value added in industry, construction, and market services, putting the country below the EU average.

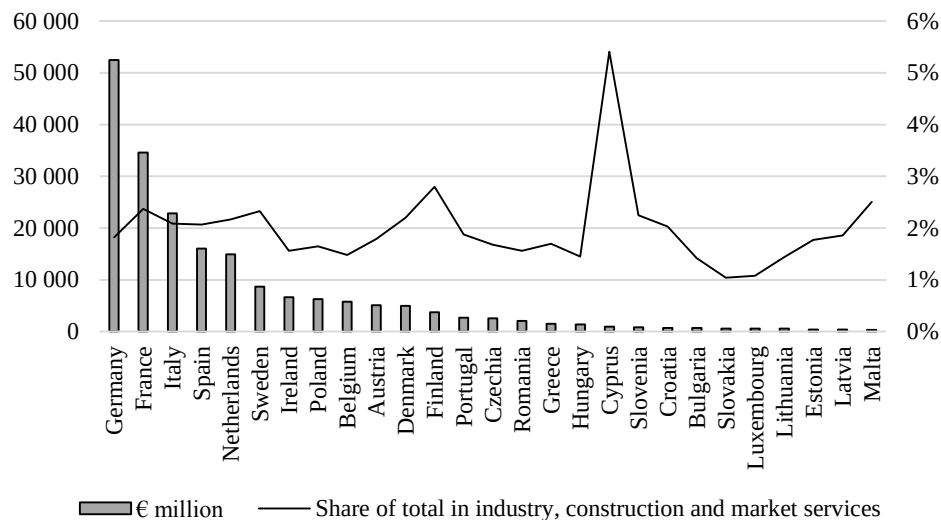


Figure 4. Value added of the cultural sector, 2022.

Source: Own elaboration based on Eurostat data.

Looking at individual cultural activities, publishing; architectural activities; and motion picture and television, music; renting of video tapes and discs accounted for the highest shares of value added (15.0%, 14.7% and 14.2% respectively), while the share of activities such as libraries, archives, museums and other cultural activities; and cultural education was negligible, standing at 0.8% and 1.2% respectively. In Poland, printing and reproduction of recorded media, manufacture of musical instruments, and manufacture of jewellery accounted for the highest shares of value added (26.2%), while the least important were the same activities as in the EU, whose share was 0.9% and 1.4% respectively.

A comparison between the value added per employee figures shows a noticeable difference between the EU average and Poland. One employee in Poland generated EUR 45,660 in value added, which accounted for 59% of the EU average, standing at EUR 77,050, despite the fact that the average number of people employed in enterprises was the same and stood at 2.0. The figures show that the cultural sector in Poland is less productive.

3.4. Trade in cultural goods

The characteristics of the economic aspect of culture also include trade in cultural goods. The analysis took into account goods that use “creation” in the production process and whose purpose is to transmit aesthetic, symbolic or artistic values, or to provide access to cultural content. They include antiques; works of art; craft articles; jewellery; books; newspapers, journals and periodicals; maps; architectural plans and drawings; photographic plates and films; recorded media; video game consoles; and musical instruments (Eurostat, 2024b).

The value of EU exports of cultural goods (taking into account only trade with external partners) in 2023 was EUR 26 billion, EUR 1.3 billion higher than the value of imports. This represents a 44.6% increase in exports and a 77.6% increase in imports over the decade. The trade balance for the EU, while still positive, decreased by 67.8%.

The analysis for individual EU Member States takes into account both intra-EU and extra-EU trade. It shows great variation between the countries. The largest exporters of cultural goods were Italy (EUR 12.4 billion) and France (EUR 10.4 billion) (Figure 5). Poland was also one of the larger exporters of cultural goods, ranking fifth with EUR 2.9 billion. Over the decade (2014-2023), the value of exports of cultural goods increased in 21 EU countries (the largest increase was in Romania, where the value was 2.65 times higher than in 2014). Poland saw an increase of 112.1%.

The largest importers in 2023 were France (EUR 9.3 billion) and Germany (EUR 8.7 billion), but the largest increase in imports was recorded in Ireland (the value of imports in 2023 was 2.6 times higher than in 2014). Only Malta and Finland reduced their imports (by 10.6% and 10.1% respectively). In Poland, imports amounted to EUR 2.5 billion, an increase of 143.7%.

Only 9 EU countries had a positive trade balance in cultural goods in 2023. The largest trade balance was in Italy (+EUR 8.2 billion), while the largest trade deficit was in Austria (-EUR 3.1 billion). In Poland, the balance was positive and stood at EUR 0.47 billion (the fourth highest figure in the EU by value).

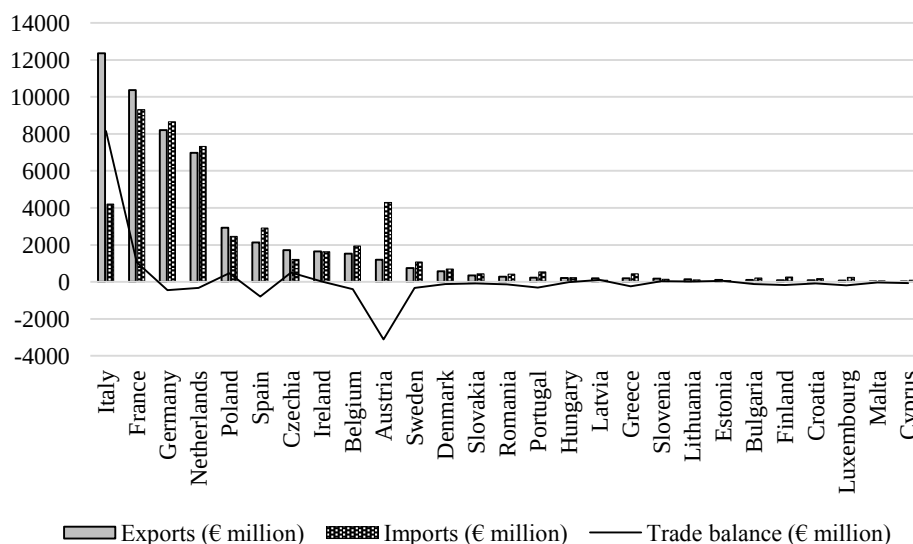


Figure 5. International trade in cultural goods, 2023.

Source: Own elaboration based on Eurostat data.

The share of exports of cultural goods in total exports in 2023 was highest in Italy (2.0%) and France (1.7%) (Figure 6). Cultural goods accounted for a relatively low share of total exports in Hungary and Finland (0.1% each), as well as in Bulgaria and in Cyprus (0.2% each). An increase in this share compared to 2014 was recorded in 10 Member States, the highest in Romania, where this share doubled. In Poland, it remained unchanged, as in Bulgaria.

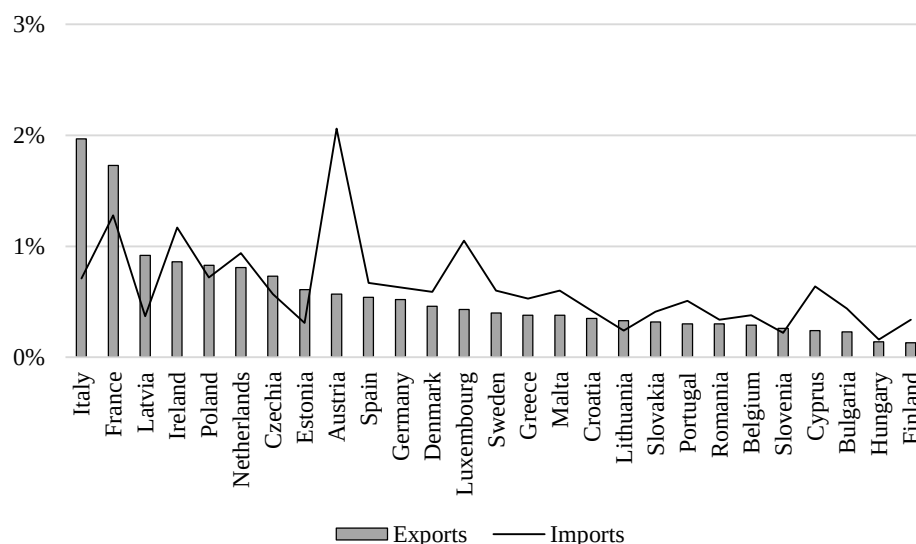


Figure 6. Share of cultural trade in total exports and imports, 2023.

Source: Own elaboration based on Eurostat data.

The share of imports of cultural goods in total imports in 2023 was highest in Austria (2.1%) and lowest in Lithuania, Hungary, and Slovenia (0.2% each). As with exports of cultural goods, the share of their imports in total imports increased in 10 countries (the most in Austria, by 67.5%, and in Ireland, by 58.5%), remained unchanged in Germany, and decreased in the remaining EU countries.

In Poland, the share of exports and imports of cultural goods in total exports and imports was 0.8% and 0.7% respectively, high figures compared to other EU countries. However, the above changes cannot be assessed positively – the share of imports increased by 20%, but the share of exports remained unchanged.

To round off the analysis of the economic importance of the cultural sector, taking into account the value added it generates, data on employment in this sector are compared with the level of per capita income. In this regard, a positive correlation can be observed. The more affluent the country, the higher the percentage of people employed in culture (Figure 7). On this basis, it can be concluded that as income rises, the importance of culture in total employment increases.



Figure 7. Percentage of people working in the cultural sector in EU countries vs. GDP per capita, 2023.

Source: Own elaboration based on Eurostat data.

4. Discussion

The results of the conducted research demonstrate that the cultural sector in the European Union plays a significant, albeit highly diversified, role with regard to employment, enterprise activity, value added, and international trade in cultural goods. The study also confirms that the potential of the cultural sector in Poland, in terms of its economic significance, remains underutilised.

The cultural sector employs a considerable number of people (622.3 thousand in Poland in 2023). However, their share in Poland's total employment (3.6%) is lower than the EU average (3.8%). The importance of the cultural sector for employment is also highlighted by the OECD (2022), which notes that employment in this sector accounted for as much as 5% of jobs in some OECD countries in 2018, and up to 10% in major cities and capital regions. Furthermore, it is estimated that around 40% of employment related to culture occurs outside the cultural sector itself (OECD, 2022).

It is important to highlight regional differences in the share of people employed in the cultural sector, with higher rates found in Western and Northern European countries.

As Bloshchynskyi (2024) points out, small and medium-sized regions often lack sufficient financial and strategic resources, and many institutions, especially in developing countries, struggle with a lack of experience and skills necessary for the effective management of cultural sector programmes. This may be due to both the insufficient number of employees and their inadequate competences in the context of development and adaptation to new conditions. Employment in the cultural sector is characterised by a much higher proportion of people with higher education than in the broader economy, as observed by Sava and Badulescu (2017). According to these authors, this demonstrates that culture requires a willingness to be acquired. This advantage may represent a key determinant of the sector's development, since, as noted by, among others, Jio and Kero (2023), Knapińska and Woźniak (2016), and Wiczerzak (2018), human capital is a source of economic growth.

The analysis of employment forms reveals greater flexibility in cultural sector jobs compared to the general economy, stemming from the specificity of activities in this sector. Due to the independent and highly specialised nature of many professions - such as authors, performers, musicians, painters, or sculptors - the cultural sector features a high share of self-employed workers (on average 31.7% in the EU). The OECD (2022) also emphasises the pronounced tendency towards self-employment in this sector, additionally noting that cultural sector workers often combine salaried positions with project-based work, thereby maintaining several jobs concurrently. While flexible employment enables autonomy and freedom in action, it may also lead to employment uncertainty, decreased social security, lower compensation, and excessive periodic workload (Berezka, 2012). Contract instability means there is greater job insecurity in the cultural sector than in other sectors (OECD, 2022).

Although significant diversity exists in this area across EU countries, these variations reflect differences in national labour markets rather than unique characteristics of cultural sector employment. In Poland, according to GUS (2025), the ratio of average employment to the number of employees in micro-enterprises was 1:5 in 2023 (for other enterprise size classes, the ratio was approximately 1:1). This indicates the majority of employees in these entities worked part-time or temporarily under employment contracts. This fact raises questions about the institutional factors and labour market policies that may encourage or restrict self-employment in the cultural sector.

Moreover, the small number of employees per company (on average two people) indicates that the cultural sector in Poland consists predominantly of small entities. This finding is confirmed by GUS (2025) data - micro-enterprises accounted for 99.1% of entities in the cultural sector in 2023. While micro-enterprises tend to be more flexible, their limited financial and human capital and restricted access to information, typical for micro and small businesses, pose significant development barriers (Stawasz, Miszczak, 2022). Other barriers limiting the sector's ability to generate value identified by Lachiewicz (2021) include low investment capacity, limited flexibility regarding the implementation of new initiatives, and heightened

risk associated with long-term innovative activity. Additionally, the high specialisation in skills means that adapting to new conditions would require retraining (Lisowska, Stawasz, 2020).

It should also be emphasised that small and medium-sized cultural enterprises have less access to external financing than SMEs in traditional sectors. This is mainly due to the intangible nature of cultural assets, which results in a lack of physical security required to obtain external financing (OECD, 2022), the niche character of certain markets, and the financial sector's unfamiliarity with cultural sector specifics (European Commission, 2024).

The significance of cultural enterprises for the economy should not be underestimated - in 2022, the cultural sector in the EU comprised 2.0 million entities, accounting for 6.3% of all enterprises. In Poland, this share was considerably lower at 4.3%. This vital role is further supported by OECD (2022) estimates, which indicate that, in 2018, cultural entities constituted on average 7% of enterprises in OECD countries.

Analysis of trade in cultural goods has shown a positive trade balance for Poland, driven by intensive exports, which should be viewed favourably compared to other EU countries. However, there is also a more dynamic increase in the share of cultural goods imports in total imports than that of exports. Notably, in countries such as Romania and Ireland, the growth rate of both exports and imports was higher, which may reflect local policies stimulating sector internationalisation or the exploitation of niche competencies. This raises questions about the effectiveness of export strategies among Polish cultural enterprises.

One cause of this situation may be the low demand for cultural goods and services, which also extends to the quality of demand. Polish society participates minimally in cultural events, and the prevailing low affluence translates into limited interest in acquiring goods from the domain of so-called high culture (Szultka, 2014). This situation is particularly relevant to young people, who cite the lack of relevance of cultural content and forms of transmission to their needs and interests, as well as unaffordable ticket prices, as major reasons for limited participation (Mazurkiewicz, Szara, 2024).

Analysis of the relationship between the share of cultural sector employment and GDP per capita points to a positive correlation between prosperity and the development of the cultural sector, prompting in-depth research into support mechanisms and structural conditions for the sector's development in developing countries.

5. Conclusions

The cultural sector is internally very diverse, which affects the ability of individual activities to generate economic and financial results. The fields that make up the "core" are characterized by different peculiarities from the cultural industries, which are at the same time different from the creative industries.

The study confirms that the cultural sector has the potential to generate socio-economic effects, promote development in many areas. It creates jobs and boosts the value of exports and value added. Its impact on the economic situation is also manifested in increased innovation in the economy, both directly and as a result of stimulating innovation in other areas.

This study focuses on the quantitative approach to the economic aspect of the cultural sector. The comparison of the results for EU countries shows great variation between the countries. Compared to other countries, Poland ranks well below the EU average. This result concerns the share of people employed in the cultural sector in total employment, the share of enterprises in this sector in total enterprises, the share of value added generated by the cultural sector in industry, construction and market services, as well as value added per capita. Although the share of exports and imports of cultural goods in total exports and imports compares favourably with the EU average, its changes since 2014 show the increased importance of imports compared to exports. Despite these changes, Poland continues to generate a positive trade balance, a positive result compared to other Member States.

The results obtained suggest that the potential of the cultural sector in Poland remains underutilized. Considering that employees in this sector are predominantly individuals with higher education, it is essential to make fuller use of their potential, especially their knowledge and creative skills. To achieve this, it is necessary to establish legal conditions that more comprehensively regulate their employment (Jurkiewicz, 2022), particularly in relation to individuals employed under civil law contracts or working on an honorary basis. A greater degree of formalization in employment would represent a desirable solution.

The analysis conducted also underscores the need to address economic conditions which involve cooperation between culture and business (European Commission, 2010), as well as with the research sector and public administration. This requires not only the development of soft skills such as trust and a willingness to pursue shared goals, but also the organization of events that serve as venues for meetings and the exchange of experiences (Szultka, 2014).

As a solution to stimulate demand for cultural goods and services, enhancing their accessibility through widely used online channels and platforms can be recommended, as this would reduce most of the identified barriers and provide access to a broader audience. However, such a solution requires investment in new technologies, training of cultural sector personnel, and changes to copyright laws. Organizational changes in the form of incentives to expand cultural activities, particularly in the virtual sphere, are also necessary.

It also appears important to take into account in legal regulations the specific nature of various types of cultural institutions, as their cost structures and business models differ significantly, which affects the way their activities are accounted for. In this context, attention should be paid to the need to modify the evaluation of these activities. This is currently carried out primarily on the basis of quantitative indicators: financial data, the number of premieres, performances or spectators, while substantive criteria such as the impact of the institution's activities on the region (Ilczuk, 2020) are not taken into consideration. The introduction of

additional evaluation criteria would strengthen the status of culture as an economic field and better highlight its economic aspect.

Another issue that should be addressed is the financing of public and local government cultural institutions. The subsidies provided by the organizing body are, on the one hand, insufficient, and on the other hand, offer a sense of security, which may result in a decline in efficiency. Therefore, the use of external capital is justified. However, traditional sources of financing are difficult to access, primarily due to the specific nature of the cultural sector - the intangible and often unique character of many of its assets. Thus, the sector's competitiveness and development require a focus on obtaining funds from venture capital, crowdfunding, or business angels. This approach also necessitates organizational changes and the introduction of incentives for seeking alternative sources of financing (Nocoń, 2023). At the same time, the level of private financing for cultural institutions is low, primarily due to the fragmentation of the cultural sector, which is made up of entities employing relatively few people, as well as a lack of awareness regarding the importance of culture for individuals and regions. Broad support for the cultural sector has therefore become important, as it may become a driving force for development in the future.

An effective solution appears to be placing greater emphasis on cultural education, which would increase awareness of the importance of culture for social and economic development among the younger generation, the future audience of cultural content. The actions undertaken will help improve access to cultural goods and services and generate higher added value. They are also necessary for shaping the adaptation and innovation skills that young people need to adjust to rapidly changing labor markets and employment patterns.

The results obtained suggest that the potential of the cultural sector in Poland is underutilised. As the people employed in it are primarily employees with higher education, it is necessary to make full use of their potential, especially their knowledge and creative skills. To this end, however, it is necessary to create legal conditions regulating the employment of these employees to a greater extent (Jurkiewicz, 2022), as well as economic conditions fostering cooperation between culture and business (European Commission, 2010). Measures designed to stimulate creativity and foster innovation will translate into the economic and financial performance of regions and the country. An economy based on culture will enable the production of more complex and innovative technologies and goods (Kaczmarek, 2019). As modern society lives in a world in which text and image, and sound and symbols play an important role, the cultural sector has great potential for development, and the development of culture is conducive to economic development.

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EXAMINING THE INFLUENCE OF SUPPLY CHAIN KNOWLEDGE ON SUSTAINABLE HOSPITAL PROCUREMENT: EVIDENCE FROM POLAND

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Purpose: The aim of the study was to assess the level of supply chain knowledge among hospital employees and analyze the impact of this knowledge on sustainable procurement in these facilities.

Design/methodology/approach: The study was based on a research questionnaire by Chiarini A. et al., which assesses sustainability requirements among suppliers. The study was conducted on a sample of 178 hospital employees in Poland. Structural equation modeling was used for the study.

Findings: Strong relationships were found between the exogenous and endogenous variables and their indicator variables, indicating that all indicator variables significantly describe the latent variables. Furthermore, supply chain knowledge among mid-level staff has a moderate impact on the frequency of sustainable sourcing activities.

Research limitations/implications: The study was conducted solely among hospital medical staff, who are not key decision-makers. Furthermore, the statistical unit in the study was employees (not healthcare providers), who may have varying levels of expertise in shaping sustainable procurement practices.

Originality/value: This study adds a new perspective to the sustainable procurement literature by examining the impact of supply chain knowledge on the frequency of actions, taking into account the mediating role of supplier and sub-supplier requirements in hospitals. The results reveal a weak mediating role of supplier and sub-supplier requirements, which provides a cognitive contribution to understanding the barriers to implementing sustainable procurement principles in the healthcare sector.

Keywords: sustainable procurement, supply chain awareness, supplier requirements, mediation model.

Category of the paper: Research paper.

1. Introduction

The contemporary healthcare system faces the challenge of providing medical care that is effective, accessible, and sustainable. The framework for action in this regard is defined by the 2030 Sustainable Development Goals, also adopted by Poland. Moreover, the deepening global climate crisis makes these goals extremely relevant, including for healthcare facilities. This results from the fact that, according to a Deloitte Report, healthcare worldwide accounts for nearly 5% of global greenhouse gas emissions, with G20 countries responsible for over 75% of this share (Global Health Care, 2024). Within healthcare, three principal categories of greenhouse gas emissions have been identified:

- facility-level emissions associated with service delivery,
- emissions generated through the use of externally purchased energy,
- supply chain emissions (Global Health Care, 2024).

Only 17% of these emissions originate directly from healthcare facilities, while the remaining share consists of indirect emissions from purchased electricity (12%) and emissions associated with the healthcare supply chain (71%) (Global Health Care, 2024). These data clearly indicate that, in the context of healthcare, the supply chain constitutes a sector that requires targeted corrective actions in the area of decarbonization.

Knowledge and understanding of the supply chain represent one of the most important factors enabling improvements in its performance (He et al., 2019), including in the context of sustainable development. However, in organizations such as hospitals, supply chains are highly complex, which makes a traditional, top-down approach to knowledge development potentially inadequate (McLaughlin, 2009) and necessitates the involvement of lower-level staff. This stems from the fact that insufficient awareness of logistics processes may lead to excessive costs, waste, and consequently increased greenhouse gas emissions, which adversely affect both the financial standing of healthcare institutions and the natural environment. A better understanding of the supply chain by all employees engaged in its operation can contribute to enhancing the quality and accessibility of healthcare services, reducing costs, and minimizing negative environmental impacts. It is also worth emphasizing that the introduction of the concept of sustainable development into supply chain management should not be perceived by organizations as a limitation, but rather as a means of improving outcomes, thereby strengthening the competitiveness of the enterprise and its supply chain organization (Chardine-Baumann, Botta-Genoulaz, 2014).

The research conducted aimed to assess the level of supply chain knowledge among hospital employees and analyze the impact of this knowledge on sustainable procurement in these units. The research was partly based on the survey questionnaire developed by Chiarini et al. (Chiarini et al., 2017), designed to evaluate sustainability requirements among suppliers. In the present

study, this questionnaire was extended to include requirements concerning sub-suppliers, as well as the participants' knowledge of the supply chain, suppliers, and sub-suppliers.

To achieve the stated objectives, the following research hypotheses were formulated:

H1: Supply chain knowledge determines the requirements imposed on suppliers.

H2: Supply chain knowledge determines the requirements imposed on sub-suppliers.

H3: Requirements imposed on suppliers determine (i.e., mediate) the frequency of actions related to sustainable procurement.

H4: Requirements imposed on sub-suppliers determine (i.e., mediate) the frequency of actions related to sustainable procurement.

H5: Supply chain knowledge determines the frequency of actions related to sustainable procurement.

This study adds a new perspective to the sustainable purchasing literature by examining the impact of supply chain knowledge on the frequency of supply chain activities. It considers the mediating role of supplier and sub-supplier requirements in hospitals. The obtained results will enable the development of recommendations for hospital managers, which may contribute to the implementation of policies fostering a more efficient and environmentally sustainable organization of supply chains in healthcare institutions.

2. Literature review

In the literature, the healthcare supply chain is defined as a sequence of physical and technical resources necessary to provide patients with high-quality service while ensuring satisfaction and cost optimization (Arora, Gigras, 2018). This chain encompasses a broad network of connections enabling the delivery of products, semi-finished goods, and raw materials to the organization. The main links of this chain include manufacturers, purchasers, suppliers, product intermediaries, and financial intermediaries (Ramakrishna, 2018; Burns 2005). Supply chain management is understood as a continuous process in which goods, services, information, and funds flow simultaneously between various participants in the chain (Srivastava, Agarwal, 2020). It should be emphasized, however, that there is no single universal model of a supply chain, as each organization possesses its own unique network of connections and relationships (Ćwik, 2011).

In light of the 2030 Sustainable Development Goals, a sustainable approach to supply chain management has become a necessity, particularly as research indicates that the implementation of sustainable supply chain practices in hospitals may generate not only environmental but also social and economic benefits (Duque-Urbe et al., 2024). These same pillars form the foundation of the ISO 20400 program for sustainable procurement, which encompasses:

1. Environmental protection (environmental benefits) - reducing the impact of products and services on the environment throughout their life cycle, with particular attention to aspects such as product energy efficiency, recycled material content, toxins and emissions, packaging, and durability.
2. Social responsibility (social benefits) - ensuring that procured goods and services support social responsibility, including issues such as working conditions, the prevention of forced labor, child labor, and human trafficking.
3. Economic prosperity (economic benefits) - supporting enterprises of various sizes, investing in research and development, and maximizing process efficiency.

Recent studies highlight the importance of knowledge, as well as collaboration and coordination, in sustainable supply chain management (Srivastava, Agarwal, 2020). Knowledge management processes are identified as catalysts that enable sustainable development at both strategic and operational levels (He et al., 2019). Research findings by Birou indicate that training and knowledge in the field of sustainability positively influence sustainable supply chain practices, which in turn lead to improved operational and economic performance (Birou et al., 2019). Similar conclusions were reached by Bartos et al., who observed that sustainability training enhances supplier performance in the area of sustainable development (Bartos et al., 2024). It should therefore be emphasized that partnerships among supply chain members are crucial and facilitate sustainable supply chain management (Teixeira et al., 2022). The complexity of processes in the context of knowledge transfer is also underlined by Ahmed et al., who argue that this complexity constitutes a significant factor affecting knowledge sharing (Ahmed et al., 2024). Knowledge transfer, in turn, holds a priority role in the supply chain, as it contributes to risk reduction (Christopher, Lee, 2004). In this context, strategic collaboration within the supply chain, focused on sharing both internal and external knowledge, gains importance, as it positively influences the overall process (Mehdikhani, Valmohammadi, 2019). Numerous studies indicate a positive relationship between knowledge and supply chain performance (Sangari et al., 2015; Alam et al., 2023; Dhaigude et al., 2021), while processes such as knowledge creation, capture, organization, storage, and dissemination have a significant impact on supply chain efficiency (Sangari et al., 2015). Furthermore, the implementation of knowledge transfer mechanisms may enhance the effectiveness of the entire supply chain (McLaughlin, 2009). Of particular importance is the effective sharing of knowledge among team members (Madani, Rungtornsupavan, 2019), especially tacit knowledge (Schoenherr et al., 2014). In summary, it can be concluded that employees' knowledge of the supply chain significantly influences its overall efficiency.

The sustainable procurement procedure involves considering environmental aspects throughout the entire supply chain, from raw material acquisition to product disposal (Beamon, 1999), which implies that the entire supply chain, including suppliers and subcontractors, should adhere to the principles of sustainable development (Chaabane et al., 2011). Consequently, all supply chain participants must comply with sustainability requirements,

and environmental criteria should also be considered when selecting suppliers (Bhardwaj, 2016), with knowledge of these criteria made accessible to all participants in the process.

To date, research on sustainable purchasing in the healthcare sector has primarily focused on identifying factors that facilitate the implementation of sustainable development principles, such as management commitment, regulatory pressure, and resource availability. The literature also emphasizes the importance of supplier collaboration and the integration of activities across the supply chain as prerequisites for the successful implementation of sustainable practices. However, relatively few studies have examined the mediating role of requirements placed on suppliers and subcontractors in this process, particularly within the context of hospital operations. To the best of our knowledge, no studies have addressed or reported on the impact of supply chain knowledge on the frequency of activities, while considering the mediating role of supplier and subcontractor requirements in hospitals. This study aims to fill this research gap.

3. Methods

Both sustainable procurement and employees' knowledge regarding the implementation of sustainable procurement activities in the supply chain are categories that are difficult to measure. For this reason, the study on the impact of supply chain knowledge on sustainable procurement in hospitals employed the structural equation modeling (SEM) method. To verify the formulated research hypotheses, the following variables were distinguished to describe hospital employees' knowledge regarding the implementation of sustainable procurement activities within the supply chain:

1. Supplier requirements - a latent variable described by the following observed variables:
 - 1_1 Demands on suppliers to comply with applicable statutory and regulatory requirements concerning environmental and safety standards.
 - 1_2 Demands on suppliers for continuous improvement of overall environmental performance over time (e.g., reduction of greenhouse gas emissions, energy and water consumption, product disposal, recyclability, material hazards, etc.).
 - 1_3 Demands on suppliers for continuous improvement of occupational health and safety performance over time.
 - 1_4 Preference for local suppliers (solely for environmental reasons, such as carbon footprint).
 - 1_5 Demands on suppliers to comply with voluntary environmental standards for products and packaging.
 - 1_6 Requests for suppliers to adhere to voluntary social responsibility standards (e.g., ISO 26000, SA8000, AA1000, etc.).

- 1_7 Demands on suppliers to comply with social requirements, such as prohibition of child labor, forced labor, discrimination, and respect for freedom of association (irrespective of the country - all are considered highly important).
2. Subsupplier requirements - a latent variable described by the following observed variables:
 - 2_1 Demands on subsuppliers to comply with applicable statutory and regulatory requirements concerning environmental and safety standards.
 - 2_2 Demands on subsuppliers for continuous improvement of overall environmental performance over time (e.g., reduction of greenhouse gas emissions, energy and water consumption, product disposal, recyclability, material hazards, etc.).
 - 2_3 Demands on subsuppliers for continuous improvement of occupational health and safety performance over time.
 - 2_4 Preference for local suppliers (solely for environmental reasons, such as carbon footprint).
 - 2_5 Demands on subsuppliers to comply with voluntary environmental standards for products and packaging.
 - 2_6 Requests for subsuppliers to adhere to voluntary social responsibility standards (e.g., ISO 26000, SA8000, AA1000, etc.).
 - 2_7 Demands on subsuppliers to comply with social requirements, such as prohibition of child labor, forced labor, discrimination, and respect for freedom of association (irrespective of the country - all are considered highly important).
3. Frequency of Actions - a latent variable described by the following observed variables:
 - 3_1 Purchase of products with packaging suitable for reuse/recycling.
 - 3_2 Purchase of products in naturally biodegradable containers.
 - 3_3 Purchase of products containing recycled materials.
 - 3_4 Purchase of “green” cleaning agents.
 - 3_5 Limiting the purchase of products with a short lifespan.
 - 3_6 Preference for purchases from local suppliers.
 - 3_7 Preference for suppliers using lower-emission transportation means (e.g., electric vehicles).
 - 3_8 Preference for suppliers whose distribution relies on a network of warehouses and connections (more efficient utilization of trucks).
4. Degree of supply chain knowledge - a latent variable described by the following observed variables:
 - 4_1 Knowledge of the origin of raw materials, goods, and services.
 - 4_2 Knowledge of the sources of suppliers’ human resources.
 - 4_3 Verification of how and by whom goods are transported.
 - 4_4 Obtaining information on the supplier’s past performance in terms of sustainability.

All variables were measured using a five-point scale:

1. For variables 1, 2, and 3, where 1 indicates no implementation and 5 indicates implementation in every purchase.
2. For variable 4, where 1 indicates no knowledge and 5 indicates having the specified knowledge for every purchase (always).

The study was conducted on a sample of 178 hospital employees in Poland: 151 employees from public hospitals and 27 from non-public hospitals. The basic characteristics of the sample are presented in Table 1.

Table 1.
Research sample characteristics

Characteristics of hospitals		Number of surveyed employees
Ownership type	Public	151
	Non-public	27
Level of reference	Clinical	68
	Voivodeship	54
	County	56

Source: Author's own elaboration.

In the first step of the research procedure, the test reliability was analyzed using Cronbach's alpha coefficient. The assessment of test reliability using Cronbach's alpha was considered appropriate because all statements derived from the conducted survey pertain to the same theoretical construct - evaluation of implemented actions in relation to sustainable procurement requirements.

Next, the relationships between the identified constructs were determined using a structural equation modeling approach, which was applied to all hospitals (Model I) and public hospitals (Model II). The model for non-public hospitals was not constructed due to the small number of cases (27). The use of structural equation modeling allows for the verification of hypotheses formulated based on theoretical considerations regarding the relationships between the variables (Nachtigall et al., 2003). Structural equation models are characterized by much greater flexibility in describing interactions between variables than multivariate regression models, particularly for qualitative variables for which the classical regression assumptions are not met (Sagan, 2003). This method is widely used in analyses focused on issues related to sustainable procurement (Mardani et al., 2020; Chandra, Kumar, 2021; Alamelu et al., 2022).

The cause-and-effect relationships between the identified variables were illustrated using a path diagram. The research model is presented in Figure 1.

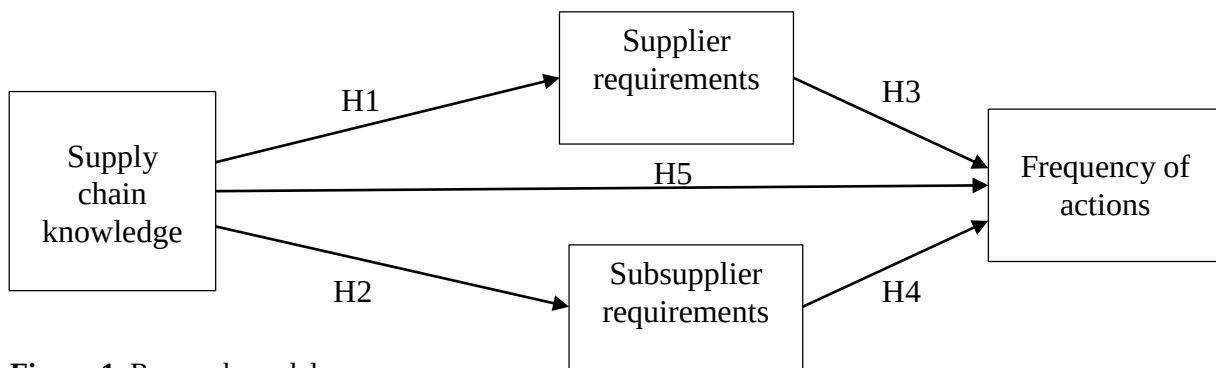


Figure 1. Research model.

Source: own elaboration.

The proposed research model represents an attempt to capture the relationships between supply chain knowledge, supplier and subcontractor requirements, and the frequency of sustainable purchasing activities in hospitals. This model serves as a basis for the empirical verification of the assumed relationships and for assessing the mediating role of supplier-related factors.

4. Results

Based on the Cronbach's alpha coefficient (Table 2), a high level of internal consistency of the test was confirmed. The obtained results indicate excellent reliability both for the analysis including all hospitals (public and non-public) and for public hospitals alone (values above 0.9).

Additionally, an analysis was conducted to determine the effect of removing an individual items from the scale concerning specific variables. The results show that eliminating any item from the set of questions does not reduce the reliability of the test below an acceptable level, and moreover, in no case does it increase the value of Cronbach's alpha. Therefore, it was concluded that there is no need to remove any questions from the test.

Table 2.

Cronbach's alpha values

	All hospitals	Public hospitals
Variable	Cronbach's alpha	Cronbach's alpha
1	0.928	0.927
	Cronbach's alpha if item deleted	Cronbach's alpha if item deleted
1_1	0.914	0.913
1_2	0.914	0.910
1_3	0.915	0.914
1_4	0.927	0.926
1_5	0.918	0.917
1_6	0.918	0.915
1_7	0.918	0.915
	Cronbach's alpha	Cronbach's alpha
2	0.935	0.927

	Cronbach's alpha if item deleted	Cronbach's alpha if item deleted
2_1	0.926	0.925
2_2	0.922	0.923
2_3	0.923	0.923
2_4	0.928	0.930
2_5	0.924	0.925
2_6	0.924	0.924
2_7	0.926	0.927
	Cronbach's alpha	Cronbach's alpha
3	0.953	0.954
	Cronbach's alpha if item deleted	Cronbach's alpha if item deleted
3_1	0.948	0.949
3_2	0.944	0.945
3_3	0.944	0.945
3_4	0.945	0.945
3_5	0.952	0.953
3_6	0.949	0.950
3_7	0.946	0.947
3_8	0.948	0.950
	Cronbach's alpha	Cronbach's alpha
4	0.958	0.958
	Cronbach's alpha if item deleted	Cronbach's alpha if item deleted
4_1	0.950	0.947
4_2	0.939	0.939
4_3	0.943	0.943
4_4	0.947	0.949

Source: Author's own elaboration.

Figure 2 presents the path diagram for Model I, constructed for all hospitals (public and non-public).

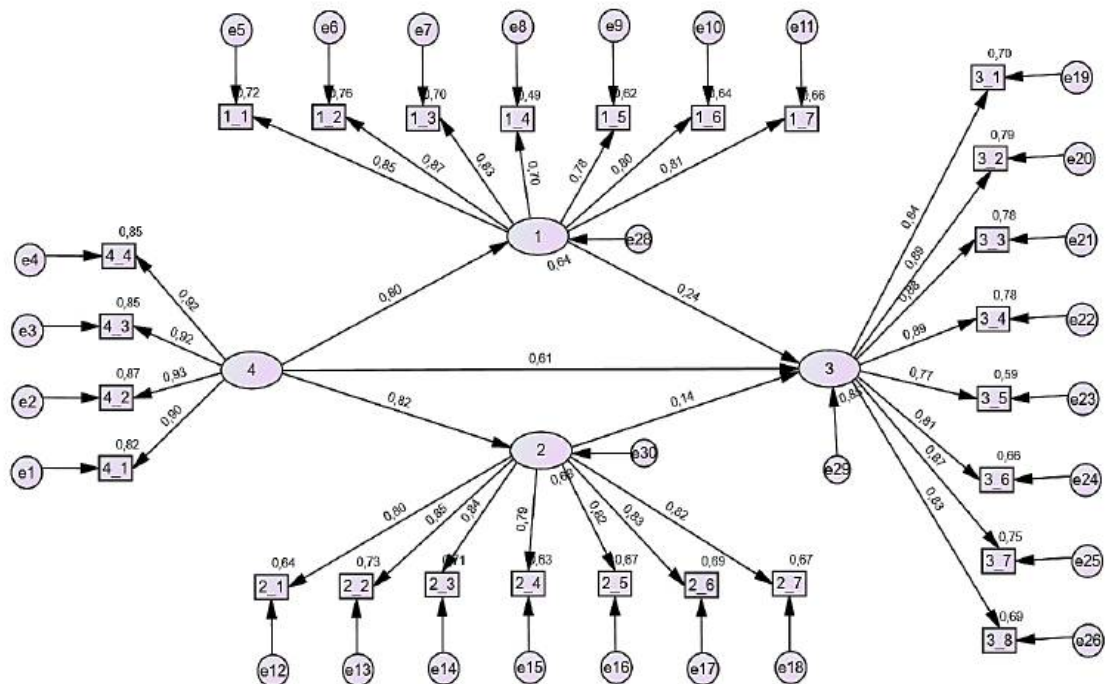


Figure 2. Path diagram for Model I (public and non-public hospitals).

Source: own calculations using IBM SPSS AMOS.

The model exhibits relatively strong relationships between the latent exogenous variable, “degree of supply chain knowledge,” and its indicator variables. All indicators are highly significant for describing this construct, with standardized regression weights ranging from 0.90 to 0.93.

Similarly, strong relationships are observed between the endogenous variables and their indicator variables. For the variable “supplier requirements”, the standardized regression weights range from 0.70 to 0.87; for “subsupplier requirements”, they range from 0.79 to 0.85; and for “frequency of actions”, they range from 0.77 to 0.89. The relationships between both exogenous and endogenous variables and their indicators should be interpreted positively - all indicator variables significantly contribute to the description of their respective constructs.

It can therefore be concluded that all indicator variables significantly and strongly influence the unobserved exogenous and endogenous variables. Moreover:

1. The degree of supply chain knowledge is best described by knowledge of the sources of suppliers’ human resources.
2. Slightly less important in describing the degree of supply chain knowledge are the verification of how and by whom goods are transported and obtaining information on the supplier’s past performance in sustainability, while the least important (though still high) is knowledge of the origin of raw materials, goods, and services.
3. Supplier requirements are best described by demands on suppliers to comply with applicable statutory and regulatory requirements concerning environmental and safety standards.
4. A less significant factor in describing supplier requirements is the preference for local suppliers (solely for environmental reasons, such as carbon footprint).
5. Subsupplier requirements are best described by demands on subsuppliers for continuous improvement of overall environmental performance over time (e.g., reduction of greenhouse gas emissions, energy and water consumption, product disposal, recyclability, material hazards, etc.).
6. A less significant factor in shaping subsupplier requirements is the preference for local subsuppliers (solely for environmental reasons, such as carbon footprint).
7. The frequency of actions related to sustainable procurement is best described by the purchase of products in naturally biodegradable containers and the purchase of “green” cleaning agents.
8. The least significant factor in describing the frequency of sustainable procurement actions is limiting the purchase of products with a short lifespan.

The main challenge in the modeling was to determine the impact of the variable “degree of supply chain knowledge” on the variable “frequency of actions”, considering the mediating role of “supplier requirements” and “subsupplier requirements”. The influence of supply chain knowledge on the frequency of actions related to sustainable procurement can be considered moderate, with a standardized regression weights of 0.61. While the relationships between supply chain knowledge and supplier requirements, as well as between supply chain knowledge and subsupplier requirements, can be regarded as strong (standardized regression weights of 0.80 and 0.82, respectively), the relationships between supplier requirements and the frequency of sustainable procurement actions, and between subsupplier requirements and the frequency of sustainable procurement actions, are weak, with standardized regression weights of 0.24 and 0.14, respectively. The following conclusions can be formulated:

1. Supply chain knowledge has a moderate effect on the frequency of actions related to sustainable procurement.
2. Supply chain knowledge has a strong effect on supplier and subsupplier requirements.
3. Supplier and subsupplier requirements have a weak effect on the frequency of actions related to sustainable procurement, indicating their limited mediating role.

Table 3 presents the goodness-of-fit measures used to evaluate Model I.

Table 3.
Model I Fit Summary

Measure	Value	Desired value
CMIN/DF	2.673	<5
NFI	0.850	≥0.9
RFI	0.834	close to 1
IFI	0.900	≥0.9
TLI	0.889	close to 1
CFI	0.900	close to 1
RMSEA	0.097	≤0.08 (values more than 0.1 indicate model rejection)
HOELTER 0.01	80	≥200

Source: calculations performed using IBM SPSS AMOS.

Analyzing the obtained values, it can be concluded that Model I exhibits a relatively low level of fit. However, this does not necessarily imply that Model I should be rejected, as fit indices such as CMIN/DF and RMSEA indicate an acceptable level of model fit. Figure 3 presents the path diagram for Model II, constructed for public hospitals.

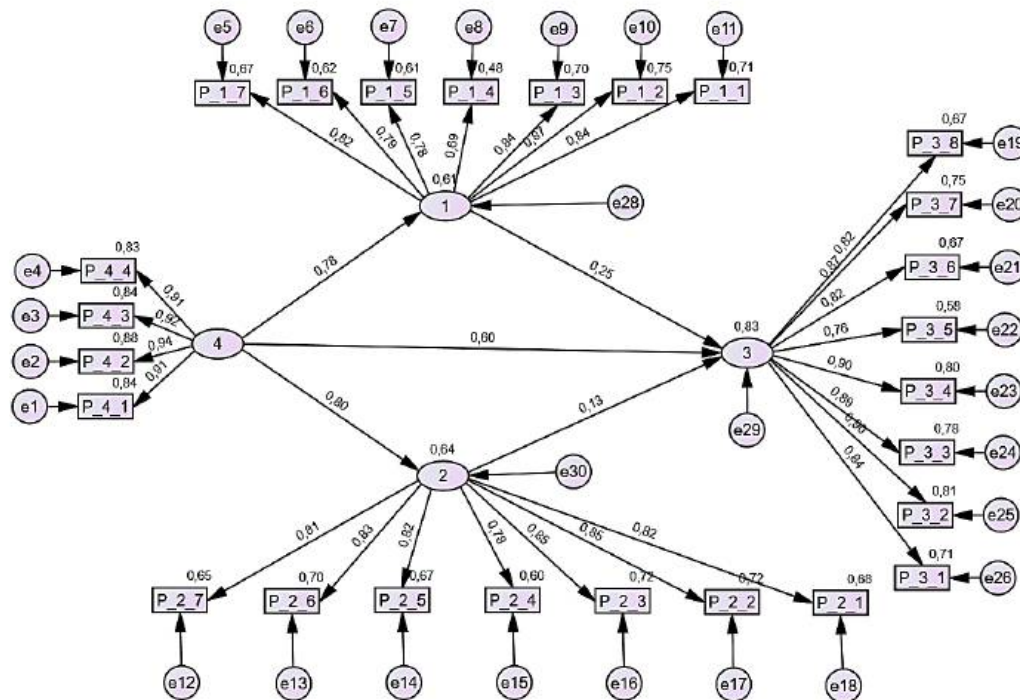


Figure 3. Path diagram for Model II (public hospitals).

Source: own calculations using IBM SPSS AMOS.

The model exhibits relatively strong relationships between the latent exogenous variable “degree of supply chain knowledge” and its indicator variables. All indicators are highly significant for describing this construct, with standardized regression weights ranging from 0.91 to 0.94.

Similarly, strong relationships are observed between the endogenous variables and their indicator variables. For the variable “supplier requirements”, the standardized regression weights range from 0.69 to 0.87; for “subsupplier requirements”, they range from 0.78 to 0.85; and for “frequency of actions”, they range from 0.76 to 0.90. The relationships between both exogenous and endogenous variables and their indicators should be interpreted positively - all indicator variables significantly contribute to the description of their respective constructs.

It can therefore be concluded that all indicator variables significantly and strongly influence the unobserved exogenous and endogenous variables. Moreover:

The degree of supply chain knowledge is best described by knowledge of the sources of suppliers’ human resources.

Slightly less important in describing the degree of supply chain knowledge is the verification of how and by whom goods are transported, while obtaining information on the supplier’s past sustainability performance and knowledge of the origin of raw materials, goods, and services are the least important (though still substantial).

Supplier requirements are best described by demands on suppliers for continuous improvement of overall environmental performance over time (e.g., reduction of greenhouse gas emissions, energy and water consumption, product disposal, recyclability, material hazards, etc.).

A less significant factor in describing supplier requirements is the preference for local suppliers (solely for environmental reasons, such as carbon footprint).

Requirements for subsuppliers are best described by demanding that they improve their overall environmental performance over time (e.g., reduction of greenhouse gas emissions, energy and water consumption, end-of-life disposal, recyclability, hazardous materials, etc.), and requiring subcontractors to improve their overall occupational health and safety performance over time.

A less significant factor in shaping subsupplier requirements is the preference for local subsuppliers (solely for environmental reasons, such as carbon footprint).

The frequency of actions related to sustainable procurement is best described by the purchase of products in naturally biodegradable containers and the purchase of “green” cleaning agents.

The least significant factor in describing the frequency of sustainable procurement actions is limiting the purchase of products with a short lifespan.

The main challenge of the modeling procedure was to determine the impact of the variable “degree of supply chain knowledge” on the variable “frequency of actions”, while accounting for the mediating role of the variables “supplier requirements” and “subsupplier requirements”. The influence of supply chain knowledge on the frequency of sustainable procurement actions can be characterized as moderate (standardized regression weight of 0.60). While the relationships between supply chain knowledge and supplier requirements, as well as between supply chain knowledge and subsupplier requirements, can be considered strong (standardized regression weights of 0.78 and 0.80, respectively), the relationships between supplier requirements and the frequency of sustainable procurement actions, as well as between subsupplier requirements and the frequency of sustainable procurement actions, are weak (standardized regression weights of 0.25 and 0.13, respectively). The following conclusions can be formulated:

Supply chain knowledge has a moderate impact on the frequency of actions related to sustainable procurement.

Supply chain knowledge has a strong impact on supplier and subsupplier requirements.

Supplier and subsupplier requirements have only a weak impact on the frequency of actions related to sustainable procurement, which indicates their limited mediating role.

Table 4.
Model II Fit Summary

Measure	Value	Desired value
CMIN/DF	2.487	<5
NFI	0.837	≥0.9
RFI	0.820	close to 1
IFI	0.896	>0.9
TLI	0.884	close to 1
CFI	0.895	close to 1
RMSEA	0.1	≤0.08 (values more than 0.1 indicate model rejection)
HOELTER 0.01	73	≥200

Source: calculations in IBM SPSS AMOS.

Based on the obtained values, it can be concluded that Model II is also characterized by a relatively low level of fit. However, similar to Model I, the values of indicators such as CMIN/DF and RMSEA indicate an acceptable level of fit for Model II.

5. Discussion

Healthcare supply chains are complex systems designed to ensure high-quality healthcare services while maintaining cost-effectiveness and adhering to sustainable development policies. Attempts to optimize hospital supply chains by transferring knowledge from traditional manufacturing have proven unfeasible due to government regulations and the unique characteristics of healthcare networks, which significantly affect the coordination of activities within these chains (Dobrzykowski, 2019). Therefore, it is necessary to identify factors specific to this type of organization that influence the quality of the supply chain. Previous studies indicate that technological readiness, organizational readiness, perceived benefits, and hospital size significantly impact hospital supply chains. Moreover, they reveal a statistically significant relationship between supply chain management practices and improvements in hospital cost performance (Bialas et al., 2023).

According to V. Roy, the key elements for improving performance in sustainable supply chains include supply chain leadership, learning orientation, knowledge management, and knowledge transfer (Roy, 2019). Previous studies have shown that both internal knowledge sharing and external knowledge sharing (with supply chain partners) positively influence sustainable supply chain management (Mehdikhani, Valmohammadi, 2019). Additionally, human capital, such as innovative idea generation and specialized expertise, has a positive impact on the performance and agility of healthcare supply chains (Mandal, 2018). The results of the conducted study indicate that the degree of supply chain knowledge is best described through knowledge. Sangari et al. highlight a strong relationship between organizational knowledge of the supply chain and supplier evaluation processes (Sangari et al., 2015). Similar

findings were reported by Patil and Kant, as well as Srivastava and Singh, who emphasized that knowledge management and knowledge sharing play a crucial role in supply chains, enabling organizations to create, build, and maintain a competitive advantage through the effective use of knowledge and collaborative practices (Srivastava, Singh, 2021; Sachin, Kant, 2013).

Considering supplier requirements, the key factors influencing supplier participation are buyer demands, government involvement, and internal readiness (Lee, 2008). Research by Ghadge et al. suggests that environmental regulations, green purchasing, and sustainable product quality are key criteria for selecting sustainable suppliers (Ghadge et al., 2018). Additionally, buyer requirements and environmental support were found to be positively associated with suppliers' willingness to engage in green supply chain initiatives (Lee, 2008). The results of the present study revealed that supplier requirements are best described by the demand for continuous improvement in environmental performance over time. However, attention should be paid to the intensity of these requirements, as efforts aimed at influencing or improving suppliers' ecological management practices raise critical issues concerning transaction costs and the overall effectiveness of such approaches for the buyer (Simpson, Power, 2005). For this reason, supplier requirements should be grounded in a collaborative model, as organizations with collaboration-based engagement also place strong emphasis on supplier support and development (Sadaat, Seuring, 2018).

The study also indicated that obtaining information on suppliers' past performance in the area of sustainability, as well as knowledge of the origin of raw materials, goods, and services, plays an important role in describing the degree of supply chain knowledge. Understanding the origin and flow of materials and goods is crucial for building efficient, competitive, and customer-satisfying supply chains (Kleab, 2017). Therefore, the enforcement of environmental requirements and supplier improvement programs based on benchmarking can be applied in combination with third-party certification (Styles et al., 2012). This is due to the fact that suppliers' environmental and social sustainability practices influence purchasing decisions and supplier selection, as they affect both the economic and relational aspects of exchange relationships (Thomas et al., 2016). The involvement of supply chain partners in acquiring and processing information on climate change is essential for managing sustainability (Dahlmann, Roehrich, 2019). Previous research also indicates a link between supply chain connectivity and information sharing within the supply chain (Khan et al., 2023).

Sustainable supply chain management requires a multi-level approach to extend sustainability practices across the entire supply chain (Hofstetter, Grimm, 2019). Consequently, it is necessary to broaden requirements not only to direct suppliers but also to sub-suppliers. Organizations should ensure the proper flow of requirements down to lower-tier suppliers as well (Rodrigues et al., 2010; Boozer et al., 2023).

In the context of hospitals, sustainable practices should be considered in the areas of hospital infrastructure, energy consumption patterns, transportation, procurement, waste management systems, and employee behaviors (McGain, Naylor, 2014). Employee behaviors, therefore,

constitute an important element in shaping the sustainable policies of hospitals, including sustainable procurement. Understanding and recognizing how supply chains function contribute to the creation of sustainable procurement patterns. The goal of hospitals should thus be to develop strategic plans that engage staff and other stakeholders in achieving the organization's environmental objectives.

6. Summary

This study analyzes the impact of the variable “degree of supply chain knowledge” on the variable “frequency of actions” in relation to sustainable procurement. It also considers the mediating role of the variables “requirements for suppliers” and “requirements for subcontractors”. The analyses were conducted for two groups of hospitals in Poland: public and non-public hospitals combined, and public hospitals only. For both groups, strong relationships were found between the exogenous and endogenous variables and their respective indicators, which indicates that all indicator variables significantly describe the latent variables. Moreover, in both groups, the knowledge of the supply chain among hospital staff had a moderate impact on the frequency of sustainable procurement activities. Although supply chain knowledge strongly influenced the requirements for suppliers and subcontractors, these requirements had only a weak impact on the frequency of sustainable procurement activities. Therefore, it can be concluded that the mediating role of supplier and subcontractor requirements in shaping sustainable procurement activities is weak.

The study, however, has certain limitations. First, it was conducted exclusively among mid-level hospital medical staff. Although this group is involved in shaping supply flows, it is not the main decision-maker in their implementation. The second limitation concerns the unit of analysis. In this research, the respondents were individual employees rather than healthcare institutions, which means that their knowledge of practices aimed at sustainable procurement may vary significantly.

The above limitations highlight the need for more in-depth research in the future, focusing on staff directly responsible for the implementation of procurement processes. It is also important to analyze procurement processes in the context of specific categories of purchased materials, which may reveal differentiated patterns and challenges in implementing sustainable procurement practices.

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DIGITAL SOCIAL RESPONSIBILITY AND THE ISSUE OF THE SEMANTIC CONCEPT OF TRUTH

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Purpose: The aim of the article is to present the meaning and function of truth understood in its semantic version for digital social responsibility. Understanding the concept of truth in the digital age seems to raise many interpretive problems. The author believes that the semantic concept of truth formulated by the Polish logician Alfred Tarski may prove helpful.

Design/methodology/approach: The article analyzes selected literature on both the understanding of the concept truth formulated on the basis of Alfred Tarski's semantic concept of truth and the possibility of its application to the digital world. Philosophical analyses of the semantic concept of truth contained in the article have been kept to a minimum and are only intended to explicate the proper understanding of this concept.

Findings: It is important to remember that a computer system operates on binary data and formal models, meaning a certain approximation of the real world. This approximation is the result of a compromise between software developers and their clients. The operation of any IT system is therefore tied to a certain agreement—an agreement to limit the image of the environment in which the IT system is to function to its most important elements. Simplifying a complex reality is necessary for its modeling. The task of an IT system is to process data.

Research limitations/implications: The article refers to a limited number of studies. The very idea of the semantic concept of truth is discussed to the extent necessary to understand the issues of algorithmic truth.

Originality/value: The article is an attempt to capture the meaning and function of truth understood on the basis of its semantic theory in the concept of digital social responsibility. Truth is an essential element of this concept.

Keywords: digital social responsibility, semantic concept of truth, Alfred Tarski, logic.

Category of the paper: Conceptual paper.

1. Introduction

This paper explores the intricate relationship between corporate digital responsibility (CDR) and the philosophical understanding of truth, particularly in an era saturated with information, misinformation, and disinformation (Søe, 2019; Rascão, 2024). The advent of

digital technologies has fundamentally altered how knowledge is produced, validated, and disseminated, introducing novel epistemological challenges such as algorithmic bias and the proliferation of intentionally deceptive content. This requires a re-evaluation of corporate obligations concerning the veracity of information circulated through their platforms and services (Lamy, 2022). Specifically, the pervasive nature of digital platforms has given rise to the concept of "algorithmic truth", where artificial intelligence systems increasingly mediate public knowledge, thereby reconfiguring the epistemic conditions under which truth is both generated and authenticated (Shin, 2025).

This paradigm shift transforms algorithmic verification into an emergent epistemic architecture, where truth is constructed through data pipelines and optimization protocols rather than traditional intersubjective deliberation or institutional scrutiny. This computational epistemology contrasts sharply with classical frameworks, where truth was dialogically constituted through human reasoning and social negotiation, raising concerns about the potential displacement of human agency in validating information (Shin, 2025). The profound implications of this shift extend to corporate responsibility, as digital entities become *de facto* arbiters of truth, often without robust mechanisms for accountability or transparency.

Consequently, a critical examination of digital corporate responsibility must address how these entities manage the epistemological challenges inherent in their operations, particularly concerning the intentional or unintentional distortion of truth (Shin, 2025). This re-evaluation must consider the "Floridian dilemma", which posits that semantic information, traditionally considered inherently truthful, may inadvertently encompass true misinformation and disinformation while excluding false misinformation and disinformation (Søe, 2019).

Outlined above complex landscape compels a deeper inquiry into the ethical frameworks guiding digital corporations, particularly as their AI technologies increasingly shape perceptions of reality and exert influence over human behavior (Swindell et al., 2024). This requires a comprehensive framework for digital corporate responsibility that transcends mere legal compliance, embracing an ethical obligation to foster an information ecosystem conducive to informed public discourse and genuine understanding (Elliott et al., 2021). This framework must acknowledge that AI algorithms, while designed for efficiency, can operate as "black boxes", making their internal workings opaque and thus challenging accountability for the information they disseminate.

The opacity of these AI systems, which synthesize disparate and often conflicting claims into confident truth-statements, necessitates a deeper examination of how corporations can be held responsible for the "operationalization of truth" within their platforms (Munn et al., 2023) (Elliott et al., 2021). This raises critical questions regarding the epistemic authority of AI systems and the potential for these systems to manipulate users who uncritically accept AI-generated outputs as objective facts.

Indeed, the uncritical acceptance of AI-generated content can lead to significant societal ramifications, as these systems, despite their sophisticated outputs, are prone to "hallucinating" false information, thereby undermining the very notion of "ground truth" (Jaton, 2021).

The semantic concept of truth, formulated by the eminent Polish logician Alfred Tarski, relativizes the concept of truth to language. However, this refers not to natural languages, but to formalized ones. They are characterized by unambiguity, meaning that each sentence has exactly one meaning. This article attempts to apply this strict definition of truth to the analysis of digital corporate responsibility. There appears to be a significant research gap in this area, which this article aims to at least partially fill. The author poses the following research question: can the semantic concept of truth be useful in the analysis of truth in the digital era and what is its relationship with Digital Social Responsibility?

2. The Concept of Digital Corporate Responsibility

CDR emerged as an extension of traditional Corporate Social Responsibility (CSR), adapting its foundational principles to the unique challenges and opportunities presented by the digital age (Radavoi, 2025; Orbik, Zozuláková, 2019). This evolution reflects the increasing digitalization of business operations and the pervasive integration of digital technologies into daily life, necessitating a re-evaluation of corporate obligations in areas such as data privacy, algorithmic fairness, and digital inclusion (Kunz, Wirtz, 2023; Trier et al., 2023).

This expanded scope considers the ethical implications of AI, blockchain, and other emergent technologies, pushing for responsible innovation and deployment that respects human rights and societal well-being (Lipare, 2023). This includes navigating the complexities of data governance, cybersecurity, and the ethical deployment of artificial intelligence to mitigate digital harms and promote an equitable digital society (Elliott et al., 2021). Central to this effort is the transparency of AI decision-making, especially as these systems increasingly influence critical domains such as financial services and healthcare, where opaque algorithms can have profound societal impacts (Olatoye et al., 2024; Elliott et al., 2021). Indeed, the "black box" nature of many machine learning algorithms poses significant challenges to accountability and fairness, demanding robust frameworks to ensure their ethical deployment and prevent the reinforcement of existing social injustices.

Businesses, therefore, bear a significant responsibility to address these concerns by adopting transparent practices and mitigating algorithmic bias to ensure AI applications uphold fairness principles (Olatoye et al., 2024; Dangar, 2025). This proactive approach necessitates a comprehensive understanding of AI's societal implications, moving beyond mere compliance to fostering a culture of ethical innovation and responsible technology stewardship (Olatoye et al., 2024). Furthermore, organizations must integrate digital ethics proactively into their

corporate social responsibility policies to build long-term sustainability and enhance stakeholder confidence (Dangar, 2025). This integration often involves establishing clear ethical guidelines for digital transformation, embracing open data principles, and actively promoting digital accessibility to ensure inclusive technological advancements. The increasing prevalence of AI and digital technologies has led to a critical examination of corporate responsibilities in preventing unintended societal consequences, such as algorithmic bias and privacy infringements (Kunz, Wirtz, 2023; Fioravante, 2024).

These phenomena require a shift towards "responsible AI" practices and robust corporate governance to manage the ethical implications of AI deployment effectively within organizational workflows (Olatoye et al., 2024). This includes rigorous impact assessments of AI systems, transparent communication about data usage, and the establishment of internal oversight mechanisms to ensure accountability in the development and application of artificial intelligence (Dangar, 2025; Kunz, Wirtz, 2023). This shift towards greater accountability in AI development is further driven by increasing regulatory activity, exemplified by initiatives like the European Union's Artificial Intelligence Act and President Biden's Executive Order on AI, which place a spotlight on the crucial role of corporations in minimizing AI risks and negative impacts (Radavoi, 2025). This highlights the growing imperative for corporations to proactively integrate ethical considerations into their AI strategies, moving beyond mere compliance to foster a culture of responsible innovation and deployment (Olatoye et al., 2024).

This involves embedding ethical AI principles within core business strategies, ensuring that technological advancements align with broader CSR objectives and societal well-being (Dangar, 2025). However, despite the growing regulatory landscape, a clear and unified message from the business sector against AI misuse remains elusive, often leading to corporations exploiting nascent governance frameworks (Radavoi, 2025). The lack of unified corporate opposition enables practices where human decision-making is outsourced to AI, thereby allowing companies to evade accountability for potential wrongdoings (Radavoi, 2025). The evasion of responsibility underscores the urgent need for a more robust ethical framework for DCR, one that explicitly addresses the challenges posed by AI in shaping public perception and understanding of truth.

The imperative to integrate ethical considerations into AI development is heightened by the potential for AI to manipulate information and perpetuate misinformation, which directly impacts the semantic concept of truth and societal stability (Dangar, 2025). Therefore, developing a coherent DCR framework for AI requires not only technical safeguards but also a philosophical grounding in how AI influences and potentially distorts shared understandings of reality (Radavoi, 2025). This framework must delineate specific corporate obligations regarding data provenance, algorithmic transparency, and the prevention of deceptive AI-generated content, thereby safeguarding the integrity of information in the digital sphere. This includes ensuring that AI systems are designed to foster fact-based communication and

mitigate the spread of misinformation, thereby upholding public trust and promoting an informed citizenry (Dangar, 2025).

Moreover, addressing the issue of semantic truth in the age of AI requires corporations to implement robust data quality assessments to curtail inherent biases and improve the efficiency and ethical integrity of their AI tools and applications (Dubey, Alam, 2024). This proactive approach is crucial, given that while scholars propose various ethical AI solutions, corporations often fail to adopt them due to the sheer volume and diversity of these proposals, leading to contradictions and uncertainty (Radavoi, 2025). This underscores the necessity for a more streamlined and universally accepted set of ethical guidelines that can be practically integrated into corporate AI development lifecycles (Weber-Lewerenz, 2021). This challenge is further complicated by the rapid pace of AI innovation, which often outstrips the development of regulatory and ethical oversight mechanisms (Tóth, Blut, 2024). Consequently, a critical gap emerges between technological advancements and the frameworks designed to govern them, necessitating adaptive and agile approaches to digital corporate responsibility. This dynamic environment demands continuous re-evaluation of ethical norms and corporate practices to ensure AI deployment remains aligned with societal values and avoids "digital ethics washing", where superficial commitments to ethics mask actual conduct (Schultz et al., 2024).

3. The Foundations of Tarski's Semantic Concept of Truth

Alfred Tarski's foundational work on the semantic concept of truth provides a framework for defining truth by articulating the conditions under which a sentence in a given language can be considered true (Tarski, 1944). This involves establishing a meta-language to define truth conditions for an object language, thereby avoiding semantic paradoxes inherent in self-referential statements within natural languages (Søe, 2016). His theory posits that a sentence is true if and only if what it states is the case, effectively linking linguistic expressions to objective reality through a rigorously defined correspondence (Tarski, 1944). Tarski's conception aligns with the classical Aristotelian view, asserting that "to say of what is that it is, or of what is not that it is not, is true" (Aristotle, *Metaphysics* G.7, 1011b26-27).

Tarski's approach, while primarily focused on formal languages, offers a robust framework for analyzing the truth-functionality of sentences, wherein the truth of compound sentences is strictly contingent on the truth of their constituent parts (Runehov, Taliaferro, 2013). The term semantic refers to the meaning of expressions (Kamp, 2013). Specifically, Tarski's extensional definition of truth dictates that all instances falling under a particular concept must satisfy the defined truth conditions (Søe, 2016). This rigorous formalization extends to understanding truth within complex systems, including the outputs of digital systems, by treating their statements

as elements within a defined object language whose veracity can be assessed against a corresponding meta-language.

However, applying Tarski's framework to digital corporate responsibility introduces significant complexities, as the "reality" against which digital pronouncements are measured is often dynamic, multifaceted, and shaped by algorithmic processes. This complexity arises because the "truth outputs" generated by algorithms often represent probabilistic classifications or embedded heuristics rather than definitive statements, diverging from classical epistemologies where truth is dialogically constituted (Shin, 2025). Consequently, the semantic evaluation of truth in digital contexts requires an adaptation of Tarski's correspondence theory to account for the computational nature of information generation and dissemination, where truth is often a function of data provenance, algorithmic transparency, and probabilistic inference rather than a direct correspondence to a static external reality (Runehov, Taliaferro, 2013; Sher, 2022). It should be remembered that Tarski's semantic conception simply indicates a method for defining the concept of a true sentence in relation to a large class of languages with a strictly defined syntax (Woleński, 2019). Therefore, in my opinion, it can also be useful in analyzing the concept of truth in AI-based systems.

This task demands a re-evaluation of traditional truth theories, moving from human-centered verification to computational epistemology, where AI models interpret truth probabilistically (Shin, 2025). The probabilistic interpretation often conceptualizes truth around "ground truth", which serves as a fundamental benchmark for training and testing data, representing an unmediated set of facts for model evaluation (Munn et al., 2023). However, the practical application of "ground truth" in complex, real-world digital environments frequently encounters challenges due to data biases, inherent ambiguities, and the dynamic evolution of information, complicating its role as an infallible arbiter of veracity (Munn et al., 2023). This re-evaluation implies that the standards of truth themselves have a history, with probabilistic approaches being a comparatively recent development in epistemology. The probabilistic methodologies, emerging in the eighteenth century alongside efforts to quantify chance, assign probabilities to "facts", thereby rendering truth conditional and relative.

Such a departure from absolute truth to a more nuanced, context-dependent understanding poses significant challenges for DCR, particularly when algorithmic systems operate with inherent opacities and their outputs are deemed factual without transparent justification (Munn et al., 2023). This change fundamentally alters the nature of epistemological inquiry, transitioning from human deliberation and contextual understanding to statistical inference and pattern matching as the primary arbiters of truth.

The concept of truth has been one of the key topics of philosophy since its beginning. This concept is important not only in philosophy or its part, epistemology, but is also important for scientific knowledge as such. The concept of truth is difficult to define (David, 2004). The expressions "true" and "false" are used in different contexts and with different meanings (Walker, 2017). Only some of their uses are philosophical in nature. The basic philosophical

meaning of these concepts refers to sentences or propositions. By propositions one means propositions, i.e., sentences endowed with a specific meaning, and by propositions one understands the meanings of such sentences. In epistemology, truth is treated as an authentic property of certain statements or propositions. The task of a philosophical theory of truth is to answer the question of what this property consists of. Various philosophical theories offer different answers to this question. The dominant theory, both in the history of philosophy and among contemporary philosophical trends, is the so-called correspondence or classical theory. Briefly speaking, it sees the nature of truth in correspondence with reality. The semantic concept of truth developed by Tarski is a version of the classical concept, mentioned above, formulated in antiquity by Aristotle. Figure 1 gives a general overview of different theories of truth.

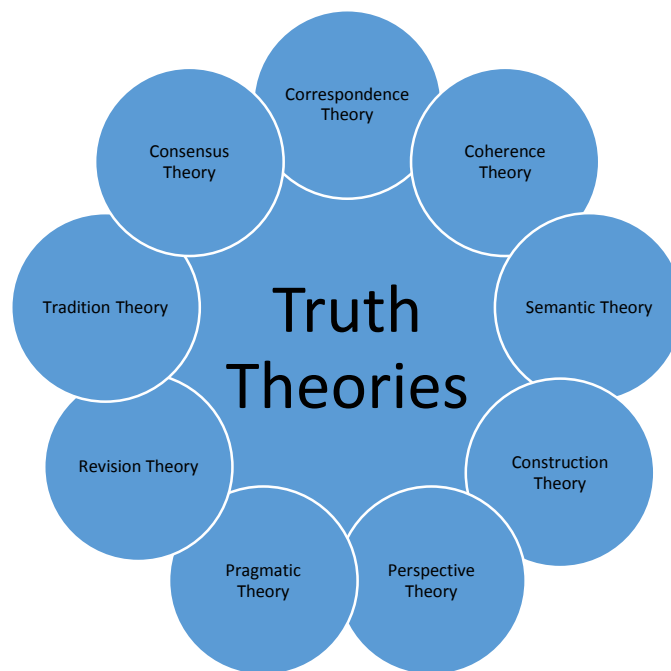


Figure 1. Theories of truth.

Source: own work.

This new epistemic logic prioritizes predictive performance over semantic meaning, leading to a reconceptualization of how veracity is established within digital systems (Shin, 2025). The transformation from traditional epistemology to computational epistemology requires a critical examination of how AI-driven systems, such as large language models, synthesize and present truth claims, often blending disparate understandings of veracity into seemingly coherent statements. This blending introduces complexities where AI outputs may appear factually coherent but lack genuine understanding or justification, challenging the traditional definition of knowledge as justified true belief (Mugleston et al., 2025). Indeed, these models, particularly generative AI, operate on statistical likelihoods of text sequences rather than an inherent understanding of meaning or factual accuracy, further complicating the assessment of truth in their outputs (Jaton, 2023). In other words, these systems operate at the syntactic level.

The probabilistic generation of content, often devoid of genuine comprehension, can lead to "hallucinations" or "botshit"—coherent-sounding but inaccurate information—thereby creating significant epistemic risks for users (Hannigan et al., 2024). These phenomena highlight the difficulty for users to calibrate their trust in AI outputs, given the inherent opacity of their data and algorithms, which often obscures the probabilistic nature of their truth claims (Heersmink et al., 2024). Furthermore, the rise of "infrastructural epistemology" demonstrates how AI systems reconfigure epistemic authority, shifting from socially deliberated truth to algorithmically determined fact labels and misinformation warnings. This transformation requires a critical examination of how users perceive and interact with AI-generated information, particularly given the observed tendency for individuals to anthropomorphize these systems and develop a sense of trust in their outputs.

4. Methods

This section outlines the research design, data collection methods, and analytical approaches employed to investigate the complex interplay between DCR and the semantic concept of truth in the age of artificial intelligence. Specifically, this study employs a mixed-methods approach, combining a systematic literature review with a qualitative content analysis of corporate responsibility reports and policy documents, to provide a comprehensive understanding of current practices and identify areas for improvement.

The systematic literature review component meticulously synthesizes existing scholarship on digital ethics, Corporate Digital Responsibility, and the philosophical underpinnings of truth in digital environments, establishing a theoretical foundation for the subsequent empirical analysis. This review also highlights the shift in corporate social responsibility to include digital ethics, addressing issues such as data privacy, artificial intelligence, and disinformation within the digital economy (Dangar, 2025; Kunz, Wirtz, 2023). The qualitative content analysis further scrutinizes how corporations articulate and operationalize their commitments to digital responsibility, specifically examining how they address data privacy, algorithmic transparency, and the prevention of misinformation in their reporting. By analyzing these documents, the research aims to identify discrepancies between stated ethical principles and actual corporate conduct, particularly concerning the potential for "ethicswashing" (Schultz et al., 2024). This dual approach allows for a robust examination of both theoretical frameworks and practical applications, offering insights into the challenges and opportunities for integrating ethical considerations into digital corporate strategies (Merbecks, 2023; Hussain, 2025).

Furthermore, the methodological framework incorporates a detailed examination of prompt engineering techniques like in-context and chain-of-thought prompting to evaluate their role in enhancing AI output quality and adherence to Responsible AI principles, thereby ensuring

fairness and accountability in AI applications (Hautamäki et al., 2024). This holistic methodology ensures a comprehensive investigation into how corporations navigate the complexities of digital ethics, aiming to bridge the gap between theoretical frameworks and practical implementation in the evolving landscape of AI-driven digital environments. By integrating these diverse analytical lenses, the study aims to generate actionable insights for policymakers and corporate leaders seeking to foster a more responsible and truth-aligned digital ecosystem.

Comprehensive analysis provides a foundation for developing more rigorous frameworks for digital corporate responsibility that explicitly address the semantic challenges posed by advanced AI systems (Schultz et al., 2024). The methodological rigor will thus allow for the identification of best practices and areas requiring further development in corporate strategies for maintaining information integrity (Olatoye et al., 2024). This includes a critical examination of how AI-driven tools, while offering significant advancements in data analysis and content generation, also introduce new complexities regarding data privacy and the potential for creating detailed individual profiles (Kunz, Wirtz, 2023). Such practices necessitate a deeper ethical inquiry into data aggregation and its implications for individual autonomy and societal trust, particularly as these profiles can be leveraged for targeted communication, potentially influencing perceptions of truth.

Moreover, the ethical dilemma is further complicated by the increasing reliance on automation and artificial intelligence in decision-making processes, which can introduce biases that disproportionately affect marginalized communities and challenge principles of fairness and justice (Dangar, 2025). Therefore, navigating these ethical challenges requires businesses to integrate robust ethical values into their digital operations, addressing dilemmas arising from digital transformation. This involves adopting open data policies and promoting algorithmic transparency to foster a more equitable digital landscape (Dangar, 2025). The study also considers the challenges and opportunities for corporate social responsibility in the digital age, particularly focusing on data security, privacy, and the spread of misinformation. This systematic approach will also shed light on how ethical governance can promote responsible and sustainable digital transformation within corporations.

The deep dive into Corporate Digital Responsibility underscores the necessity for companies to not only understand but also actively mitigate the ethical implications of advanced AI and interactive marketing (Kunz, Wirtz, 2023). This includes a critical examination of how AI-driven tools, while offering significant advancements in data analysis and content generation, also introduce new complexities regarding data privacy and the potential for creating detailed individual profiles (Saura et al., 2024; Kunz, Wirtz, 2023). The ethical implications intensify when considering the automation strategies employed for massive data collection, which inherently link to the profitability of AI-based digital marketing actions. Such practices require a deeper ethical inquiry into data aggregation and its implications for

individual autonomy and societal trust, particularly as these profiles can be leveraged for targeted communication, potentially influencing perceptions of truth (Sarioguz, Miser, 2024).

5. Literature review

This section explores the confluence of the semantic concept of truth and DCR, examining how the digital economy necessitates a re-evaluation of fundamental assumptions regarding corporate accountability and the nature of truth in a technologically mediated environment (Lankoski, Smith, 2021; Ogbujah et al., 2022). The pervasive influence of digital technologies has fundamentally reshaped corporate social responsibility, integrating concerns such as data privacy, algorithmic fairness, and the ethical implications of artificial intelligence into its purview (Hwang, 2024; Dangar, 2025). This expansion has led to the emergence of "corporate digital responsibility", a holistic approach addressing both the opportunities and risks presented by digitalization to ensure ethical behavior and contribute to human and social value creation (Carl, Hinz, 2024). This requires a critical examination of how truth is constructed and disseminated within digital ecosystems, particularly as companies increasingly leverage digital tools that can influence perception and reality.

This situation underscores a paradigm shift where truth becomes algorithmically determined rather than socially deliberated, leading users to exhibit automation bias by deferring to AI outputs even when explanatory transparency is lacking (Shin, 2025). This phenomenon necessitates a comprehensive review of the ethical implications of AI deployment in business, emphasizing responsible AI practices and corporate accountability (Olatoye et al., 2024). It is also important to remember the impact of the use of various AI-based technologies and computational methods on various contexts of human social life (Suchacka, 2019).

The rapid advancement of digital technology, while offering increased productivity and global interconnectedness, has also introduced significant ethical challenges, including the spread of misinformation (Dangar, 2025). This phenomenon introduces a "Floridian dilemma", where semantic information, traditionally considered inherently truthful, may inadvertently encompass or even actively propagate certain forms of misinformation and disinformation, thereby blurring the lines between fact and falsehood in the digital realm (Søe, 2019). Consequently, corporate digital responsibility must encompass strategies for mitigating the dissemination of such "true misinformation" and "true disinformation", given that these can arise even from well-formed, meaningful data (Van der Merwe, Al Achkar, 2022). This necessitates a robust framework for discerning digital truth from non-truth, especially given the simultaneous circulation of both within digital media, often without clear distinctions (Rascão, 2024).

The challenges extend beyond merely identifying falsehoods, as the digital environment can also render certain truths "useless" or obscure them amidst an overwhelming volume of information (Rascão, 2024). Corporate digital responsibility, therefore, must develop sophisticated mechanisms for content authentication and provenance tracking to ensure the veracity of information disseminated through their platforms (Stahl, 2024; Pappas et al., 2023). Furthermore, the ethical implications of AI, such as biased algorithms trained on skewed datasets, underscore the urgent need for businesses to prioritize accountability, transparency, and equity in their digital practices (Wirtz et al., 2022). This includes establishing ethical AI frameworks and governance structures to enhance corporate integrity and mitigate inherent biases, especially given the expansive scope of rapidly advancing technologies and their omnipresence (Tóth, Blut, 2024; Kunz, Wirtz, 2023).

The very concept of a "digital truth" is emerging as a critical construct, demanding a universal definition not only for scientific research but also for guiding human conduct and decision-making in the digital age, fostering harmony, peace, and socio-economic well-being. This universal digital truth, therefore, is posited as a conscious human action rooted in decision-making that respects human dignity (Rascão, 2024). This concept underscores the critical need for corporations to integrate ethical considerations into every aspect of their digital operations, moving beyond mere compliance to proactive engagement in shaping a responsible digital future. This involves a commitment to transparency in AI algorithms and decision-making processes, ensuring that technological advancements align with ethical standards and societal values to build trust among stakeholders (Olatoye et al., 2024). This focus on transparency and ethical alignment is particularly vital in mitigating the potential for AI-generated content to create a false sense of authenticity and authority, which can (Kim, Kong, 2023). Furthermore, the integration of AI into business processes necessitates a thorough understanding of responsible AI practices to ensure that technological advancements align with ethical standards and societal values (De Blasio, Selva, 2021).

Organizations must, therefore, prioritize the implementation of robust ethical AI frameworks, encompassing principles of fairness, accountability, and transparency, to navigate the complexities of AI deployment responsibly and sustain stakeholder trust. This proactive approach is essential for preventing the erosion of public trust that can result from opaque or biased algorithmic decision-making (Olatoye et al., 2024). Moreover, responsible AI practices require continuous evaluation and adaptation, as the evolving nature of AI systems can introduce unforeseen ethical dilemmas that demand proactive mitigation strategies.

Moreover, the ethical imperative for corporations extends to safeguarding data privacy and security, advocating for responsible data handling practices in an era where vast amounts of personal information are routinely collected and processed. This includes establishing clear standards for data governance, conducting regular external audits, and fostering an equitable power dynamic within digital service ecosystems to protect customer privacy and mitigate

potential harms. his commitment necessitates adopting frameworks that prioritize data dignity, treating user data as an extension of personal identity requiring meticulous ethical handling throughout its lifecycle (Saura et al., 2024).

A separate issue related to the semantic concept of truth is its significance for logic. However, this issue is not discussed in this article because it concerns a topic that is not directly related to the subject under discussion. In the most general sense the semantic concept of truth in logic, largely formalized by Alfred Tarski, provides a rigorous framework for defining what it means for a statement to be true within a given formal language. Tarski's seminal work in the 1930s laid the groundwork for the modern logico-mathematical Theory of Models, enabling the association of formal signs with their corresponding objects in an underlying structure (Longo, 2019; Tarski, 1944). This approach fundamentally treats truth as a semantic property, focusing on the relationship between linguistic expressions and the objects or states of affairs they denote.

This paper explores the intricate relationship between the philosophical concept of truth, particularly in its semantic dimension, and the emergent field of digital social responsibility, critically examining how digital environments necessitate a re-evaluation of both concepts. The pervasive influence of digital technologies on societal moral systems necessitates a systematic investigation into how these platforms transform fundamental human values, such as truth and trust (Danaher, Sætra, 2022).

6. Results and Discussion

This research offers a significant theoretical contribution by bridging the hitherto disconnected fields of DCR and the semantic concept of truth, thereby advancing our understanding of ethical considerations in the digital sphere (Carl, Hinz, 2024; Herden et al., 2021). Specifically, it introduces a novel framework that integrates principles of semantic accuracy into the operationalization of DCR, addressing critical issues such as algorithmic bias and misinformation prevalent in digital communication (Dangar, 2025; Rascão, 2024). Furthermore, this interdisciplinary approach illuminates how digital technologies, particularly AI, reshape corporate responsibilities beyond traditional CSR frameworks, demanding a re-evaluation of how truth is constructed and maintained in digital interactions (Schultz et al., 2024). This becomes especially important in the post-truth era, when narratives often take precedence over truth, which is blurred and distorted (Surahman, 2024). In this situation, it becomes necessary to develop clear criteria for assessing the veracity of digital information, which in turn presupposes an understanding of truthfulness.

It also highlights the imperative for companies to proactively develop and implement robust internal mechanisms and external auditing procedures to ensure the veracity of digital information, thereby fostering greater transparency and accountability in their digital ecosystems (Dangar, 2025). Moreover, this framework extends beyond mere compliance, proposing that genuine commitment to semantic truth in digital contexts can enhance stakeholder trust and cultivate long-term reputational advantages. By articulating the intricate relationship between data ethics, algorithmic transparency, and the fidelity of digital communication, this work offers a foundational understanding for future research into responsible AI deployment and ethical data governance.

It additionally posits that the evolving landscape of digital communication necessitates a redefinition of CSR to incorporate digital ethics, moving beyond traditional philanthropic and environmental concerns to address the profound impact of technology on societal perceptions of reality (Kargbo et al., 2025). It requires a strategic shift towards embedding ethical considerations at every stage of digital product development and service delivery, ensuring that technological advancements align with broader societal values (Kunz, Wirtz, 2023). This redefinition is crucial as AI-driven systems increasingly shape information dissemination and public discourse, thereby influencing epistemic production and the very notion of truth itself. The inherent complexity of generative AI, for instance, challenges established notions of content authenticity and requires novel approaches to verifying information (Kim, Kong, 2023). It represents a paradigmatic change where truth becomes algorithmically determined rather than socially deliberated, leading to an infrastructural epistemology where truth is computed, not argued.

The above mentioned conceptualization underscores the urgency for corporations to engage with the ethical implications of AI, recognizing that the systems they deploy actively shape public understanding and the validation of knowledge (Shin, 2025). Such a programmatic approach to truth, where algorithms determine what is considered valid, demands a re-evaluation of accountability frameworks, particularly concerning the ethical implications of data pipelines and optimization protocols. This, in turn, highlights the need for a detailed analysis of how architecture and technical infrastructure interact with social relations and cultural norms to produce distinctive forms of truth (Munn et al., 2023). It requires a robust framework for algorithmic transparency and accountability, ensuring that the methodologies underlying AI-driven truth claims are open to scrutiny and subject to ethical oversight.

Moreover, integrating artificial intelligence into corporate communication requires a critical analysis of how these systems might perpetuate or mitigate existing biases, thereby influencing the perceived credibility and fairness of information presented to stakeholders (Buhmann, 2023). Therefore, robust structural mechanisms ensuring enforceability, transparency, and redress become essential to counteract potential "ethical whitewashing" and ensure true accountability in AI governance (Ibitoye et al., 2025). This includes developing clear protocols for addressing algorithmic bias and implementing mechanisms that enable stakeholders to

challenge AI-generated outcomes, going beyond technical solutions and supporting systemic epistemic justice (Oguz, 2025). Such approaches are crucial for navigating an evolving landscape in which AI systems not only detect falsehoods but also actively construct particular versions of truth, deeply embedded in their sociotechnical design.

The operationalization of truth within AI systems, particularly large language models, synthesizes often-conflicting claims into smoothly presented truth-statements, highlighting a shift from deliberative knowledge production to probabilistic inference (Munn et al., 2023). Algorithmic determination of truth, derived from training pipelines and heuristic logic, often leads users to exhibit automation bias, deferring to AI outputs even without explanatory transparency (Shin, 2025). This requires a critical evaluation of how such systems reconfigure epistemic authority, potentially displacing human reasoning with probabilistic automation.

The issues outlined above point to the need to develop a DCR framework that considers not only the factual accuracy of AI-generated content but also the mechanisms underlying its perceived veracity and potential manipulation (Munn et al., 2023). Therefore, understanding the social shaping of AI truth claims, from data acquisition to user interaction, is crucial to developing effective DCR strategies (Munn et al., 2023). To minimize these risks, organizations must adopt a proactive approach by incorporating ethical considerations into the design, development, and implementation phases of AI systems, moving beyond reactive compliance (Zhao et al., 2025). Such proactive approach requires a focus on resolving issues quickly, thereby protecting stakeholders and demonstrating a commitment to responsible AI practices. Figure 2 illustrates the relationship between digital corporate responsibility and the semantic concept of truth.

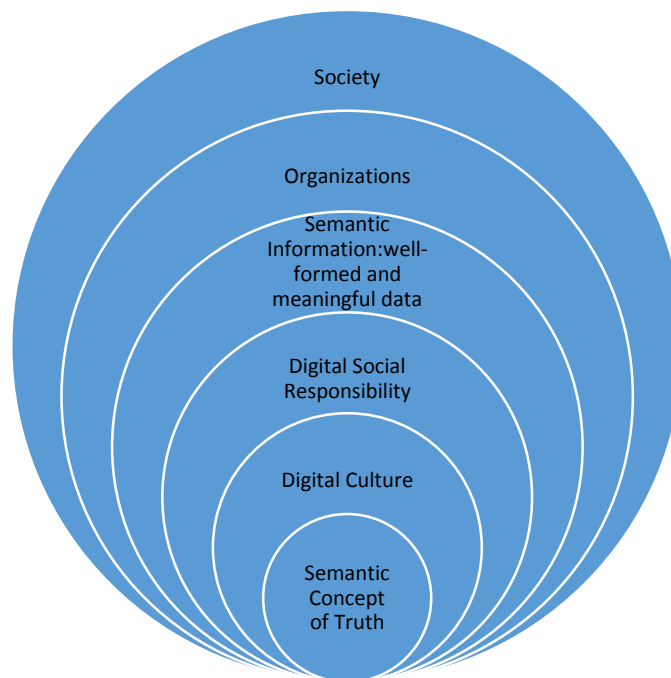


Figure 2. The scope of influence of DSR and the Semantic Concept of Truth.

Source: own work.

The analyses presented above suggest that developing a robust framework for algorithmic transparency and accountability is crucial to mitigating the risks associated with AI-generated content, ensuring users can clearly identify the origin and potential biases of information (Olatoye et al., 2024). Furthermore, future research should focus on developing new epistemic tools and educational initiatives aimed at improving digital literacy, enabling individuals to critically assess the veracity of information encountered in increasingly complex algorithmic environments. Further research is also needed on the long-term psychological and sociological impact of ubiquitous AI-generated content on human cognitive processes and social trust mechanisms.

7. Summary

This article has explored the complex interplay between DCR and the semantic concept of truth in the age of AI. It has emphasized how algorithmic truth, embedded with normative assumptions and data-driven biases, reconfigures epistemic authority and necessitates robust frameworks for transparency and accountability in AI systems (Shin, 2025; Olatoye et al., 2024). Further research is imperative to delineate specific mechanisms by which corporations can ensure the veracity of AI-generated content and foster public trust in automated decision-making processes.

The answer to the research question posed in the Introduction seems positive. The research significantly advances the theoretical understanding of DCR by integrating it with the nuanced philosophical underpinnings of the semantic concept of truth, thereby offering a more robust framework for evaluating corporate conduct in the digital age. It also provides actionable insights for organizations to develop and implement ethical digital strategies that foster transparency and maintain stakeholder trust (Herden et al., 2021).

Furthermore, it highlights the critical need for continuous interdisciplinary research to address the evolving ethical challenges posed by rapid digital transformation and the increasing importance of human-centric approaches in technology (Pappas et al., 2023; Dangar, 2025). The work elucidates the necessity for a paradigm shift in corporate digital ethics, moving beyond mere compliance to embrace a proactive stance on truth preservation and dissemination (Carl, Hinz, 2024). Such a paradigm requires a deeper exploration into the epistemological foundations of digital information and its impact on the collective understanding of reality, urging corporations to prioritize verifiability and authenticity in their digital interactions.

This involves developing sophisticated frameworks for data provenance and integrity, ensuring that information disseminated through digital channels can be traced to its origin and verified for accuracy (Ateeq, Milhem, 2024). Moreover, this framework extends to scrutinizing

algorithmic biases and their potential to distort information, underscoring the imperative for corporations to ensure that their digital tools and platforms uphold semantic truth.

Such a commitment to semantic truth also extends to the ethical development and deployment of AI, where transparency in algorithmic decision-making and accountability for outputs are paramount to maintaining stakeholder trust and adhering to societal values (Olatoye et al., 2024). The integration of AI, IoT, and blockchain technologies presents both opportunities and challenges in this regard, necessitating robust governance structures to ensure these technologies contribute to, rather than detract from, the pursuit of truth and accountability (Florek-Paszkowska, Ujwary-Gil, 2025; Lei et al., 2023). Specifically, the intersection of these technologies demands a re-evaluation of traditional notions of truth verification, moving towards a computational epistemology where truth becomes a probabilistic function rather than a deliberative outcome.

It requires robust ethical guidelines, algorithmic transparency, and continuous bias detection to secure truth in communication during the generative AI era (Kim, Kong, 2023). Implementing this project requires a proactive, ethics-by-design approach for AI development, ensuring that these systems are built with mechanisms to uphold semantic truth and prevent the propagation of misinformation, thereby aligning technological advancements with societal values (Weber-Lewerenz, 2021; Olatoye et al., 2024). The current arms race among trillion-dollar corporations in developing AI technologies further exacerbates the complexity, as their pursuit of increased user engagement through AI-driven platforms risks creating an ecosystem rife with misinformation and conspiracy theories (Swindell et al., 2024). This urgent situation underscores the necessity for comprehensive regulatory frameworks and corporate responsibility initiatives to mitigate the potential for AI to erode the semantic concept of truth within the digital sphere (Kim, Kong, 2023). Therefore, distinguishing truth amid the rapid development of AI technologies requires a bifurcated approach addressing both front-end and back-end AI concerns to enhance transparency and mitigate algorithmic biases.

Swindell et al. (2024) point out that the current arms race among trillion-dollar corporations developing AI technologies further exacerbates this complexity, as their pursuit of increased user engagement through AI-driven platforms risks creating an ecosystem rife with misinformation and conspiracy theories. This situation highlights the need for comprehensive regulatory frameworks and corporate social responsibility initiatives to mitigate the risk that AI could undermine the semantic concept of truth in the digital sphere (Kim, Kong, 2023). Therefore, discerning truth in the face of rapid AI technology development requires a decoupled approach, addressing both front-end and back-end AI issues to increase transparency and mitigate the risks.

Front-end AI strategies focus on making AI-generated content more transparent and explainable, while back-end AI aims to improve the underlying algorithms to reduce inherent biases. Such a dual approach, encompassing both user-facing transparency and internal algorithmic integrity, is crucial for preserving the semantic concept of truth in an increasingly

AI-driven information landscape. This dual approach is essential for preventing the dissemination of disinformation and maintaining public trust in digital communication channels (Kim, Kong, 2023). This robust framework ensures that corporations actively contribute to a more truthful and transparent digital environment, aligning their operational practices with the fundamental principles of semantic truth.

Our analysis revealed that the unchecked proliferation of AI-generated content, particularly from front-end AI, significantly challenges the semantic concept of truth by fostering disinformation and blurring the lines between authentic and manipulated information. This paradigm shift transforms truth into an algorithmically determined outcome, rather than a product of social deliberation, leading users to often accept AI-generated information as objective despite its computational origins.

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NEW TOOLS, NEW EXPECTATIONS: THE LEVEL OF ACCEPTANCE AND INTEREST IN IMMERSIVE TECHNOLOGIES AMONG GENERATION Z. EVIDENCE FROM POLAND

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Purpose: The aim of the study is to analyse the level of interest in using innovative tourism products among Generation Z, including products based on immersive technologies.

Design/methodology/approach: The research methods were based on an online survey (CAWI) conducted among 185 young tourists from Poland, following the TDM methodology.

Findings: The findings extend existing theoretical discussions on the role of technological advancement in shaping contemporary travel experiences, confirming that innovation acceptance among young tourists depends not only on techno-logical sophistication but also on perceived usefulness, simplicity, and emotional value. An important direction for the development of product innovations is their considerable diversity, based on niche tourist preferences. This will allow personalization of tourism offers and accessibility to diverse tourist segments.

Research implications: This study contributes to the growing body of research on Generation Z's tourism behavior by identifying the differentiation in their attitudes toward immersive and non-immersive innovations and by integrating these insights into the broader framework of innovation adoption in tourism.

Practical implications: the study provides tourism enterprises and destination managers with evidence that smart, user-friendly technologies, those embedded in daily travel routines—should remain the core focus of product development, while immersive solutions such as VR, AR, and AI should be gradually introduced as complementary tools enhancing the sensory and experiential dimensions of travel. The research also suggests that communication strategies aimed at Generation Z should emphasize authenticity, interactivity, and personalization rather than purely technological novelty.

Originality/value: Generation Z seeks new, emotionally engaging, and unique travel experiences, preferring technologies that enhance comfort and personalization. Advanced digital tools play a complementary role, highlighting the need for the gradual implementation of innovations that integrate functionality with authentic and tangible travel experiences.

Keywords: tourism innovation; generation Z; digital tourism; technology adoption; tourist experience.

Category of the paper: Research paper, Case study.

1. Introduction

Rapid socio-cultural, technological, economic, and health-related changes are leading to the implementation of innovations—particularly radical product innovations—within tourism service offerings. However, existing studies indicate that tourism services still lag these changes, especially technological ones, with incremental, imitative, and adaptive innovations remaining dominant (Panfiluk, 2021).

Tourism service offerings should meet the expectations of all participants in the tourism market, including Generation Z. Generation Z represents an entirely different tourism segment, displaying distinct personality traits and behaviors compared to previous generations. It is characterized by high digital competence, a natural presence in social media environments, and a strong need for interactive, emotional experiences and online information exchange (Stepaniuk, Misiewicz, 2025; Khoo-Lattimore et al., 2019).

In their online behavior, there is a tendency to imitate the behaviors of other users, resulting from two mechanisms: herd behavior — succumbing to group influence and replicating the majority's actions—and behavioral mimicry — imitating the emotions and reactions of observed users (e.g., idols, friends, influencers). This translates into a strong influence of feedback, authority figures, and popular content (Stepaniuk, Misiewicz, 2025).

Their cognitive and emotional behaviors in VR/AR environments are determined by factors such as immersion, interactivity, and visualization, which affect their travel decisions and engagement with tourism content (Khoo-Lattimore et al., 2019). They expect personalized service offerings from tourism providers—distinct from everyday experiences (Elshaer, Marzouk, 2024).

A response to these expectations and the future breakthroughs in the tourism industry may be radical product innovations built on advanced technologies and artificial intelligence (Sigalat-Signes et al., 2020); Buhalis et al., 2023). These innovations enable visitors to experience events in ways impossible in the real world (Buhalis, Sinarta, 2019). They also have a profound impact on the creation of strong emotions and experiences during exploration, which translates into enhanced tourism experiences (Liberato et al., 2018). An analysis of the literature on Generation Z's tourist behavior and its relationship with innovation and information technologies reveals several significant research gaps that limit a full understanding of this consumer group and its role in the future development of tourism. (Robinson, Schänzel, 2019a) point out that the literature concerning Generation Z remains very limited, especially within academic research. Most available works are marketing reports and market analyses, with a lack of in-depth scientific studies addressing their motivations, experiences, and travel behaviors. The authors observe that most studies address planning processes and motivations rather than actual travel behavior. Consequently, empirical knowledge concerning the real behavior of young tourists within destination environments remains limited.

The shortage of research on the interests, behaviors, and tourism expectations of Generation Z is also confirmed by Haddouche & Salomone, (2018), Skinner et al., (2022), Entina et al., (2021). Zhou et al., (2023) emphasize that most studies focus on intentions rather than on actual actions undertaken by users during trips. Tavakoli & Mura, (2015) further confirm that too many studies are conceptual or technology-oriented, with few examining real tourist responses (Tavakoli, Mura, 2015). Khoo-Lattimore et al., (2019) note a continued lack of observational and experimental research on user behavior in VR/AR tourism contexts. Konieczna & Trybuś-Borowiecka, (2025) highlight a shortage of analyses regarding attitudes toward innovative tourism solutions, such as mobile applications, virtual reality (VR), or artificial intelligence (AI). As they observe, representatives of Generation Z “do not fully utilize” the potential of modern technologies in the travel process, despite being their natural users. This gap is supported by research in the gastronomy sector conducted by Meeprom et al., (2025), who indicate that knowledge about the impact of product novelty and risk perception on the acceptance of innovation among young consumers remains very limited—even though this group demonstrates high openness to experimentation and new sensory experiences. Moreover, there is a regional gap, as most studies are case studies conducted in diverse geographical areas and socio-economic conditions, focusing primarily on highly developed countries. Therefore, there is a clear need for data from other regions, including Central and Eastern Europe (Robinson, Schänzel, 2019; Vestola, Kirsten, 2025).

In summary, the current state of research indicates that although knowledge about Generation Z as tourism consumers is gradually expanding, there remains a weak connection between innovation theory and consumer behavior and tourism practice. There is a shortage of empirical analyses concerning actual behavior and the use of innovative products in the travel practices of Generation Z. The aim of the study is to analyze the level of interest in using innovative tourism products among Generation Z, including products based on immersive technologies.

The article consists of four parts. The first part provides a literature review focusing on trends in the development of innovative tourism products and the current state of research on Generation Z's tourism preferences and expectations. The second part discusses the research methodology. The third part presents the results of a study conducted among Generation Z tourists. The fourth part expands on the findings and includes a discussion. The article concludes with conclusions, theoretical contributions, practical implications, and limitations related to future.

2. Innovations in Tourism and the Consumption Patterns of Generation Z Tourists - Literature review

2.1. Innovations in the Tourism Services Market

Implementing product innovations in tourism services is the only way for enterprises to adapt to an increasingly aware and demanding consumer. This challenge is complex, as the tourism industry is recognised as a sector with a low level of innovativeness. It is dominated by imitative, incremental and adaptive innovations, often referred to in the literature as secondary innovations (Sundbo et al., 2007; Hjalager, 2010; Krizaj et al., 2012; Allsos et al., 2014; Pozzo et al., 2023; Panfiluk, 2021). Booyens & Rogerson (2016) report that three-quarters of implemented innovations are incremental, whereas only one-quarter of surveyed enterprises introduce novel innovations with varying market reach (Panfiluk, 2021). Most effects of implemented innovations are visible only at the regional level (Camisón, Monfort-Mir, 2012). Despite this, the implemented innovations have enhanced both the quality of customer service and the tourism experience in the real world, stimulating the senses, emotions, taste and aesthetic appreciation (Pricope Vancia et al., 2023). Contemporary innovations based on advanced technologies and artificial intelligence enable experiences that cannot be achieved in physical reality (Koohang et al., 2023). It is recognised that they will drive future breakthroughs in the tourism industry (Sigalat-Signes et al., 2020; Sigala, 2023).

The first group consists of innovations developed using operational IT technologies — smart technologies Robinson & Schänzel (2019), also referred to as empathetic digital solutions (Zhang et al., 2025). These are practical, everyday innovations embedded in the natural rhythm of life (Zhou et al., 2023), allowing intuitive and natural use during travel without technological barriers — a characteristic feature of Generation Z (Robinson, Schänzel, 2019). They streamline everyday tourism practices by providing simplicity and functionality in areas such as payments, planning, booking and communication (Konieczna, Trybuś-Borowiecka, 2025; Zhou et al., 2023; Ratna et al., 2024; Robinson, Schänzel, 2019).

Two main categories of innovations can be distinguished. The first comprises innovations based on operational IT technologies – smart technologies (Robinson, Schänzel, 2019), also referred to as empathetic digital solutions (Zhang et al., 2025). These are practical, everyday solutions embedded in the natural rhythm of life (Zhou et al., 2023), intuitive and seamlessly accompanying travel without technological barriers, which is typical for Generation Z (Robinson & Schänzel, 2019). They enhance everyday tourism practices, offering simplicity and functionality in areas such as payment, planning, booking and communication (Konieczna, Trybuś-Borowiecka, 2025; Zhou et al., 2023; Ratna et al., 2024; Robinson, Schänzel, 2019).

The second category includes products and services based on immersive digital technologies, such as blockchain, artificial intelligence (AI), augmented reality (AR), virtual reality (VR) and mixed reality (MR) – the metaverse (Buhalis et al., 2023). These solutions

transform the way tourism services are designed, delivered and experienced, enhancing efficiency, personalisation and user value (Zhang et al., 2025; Ratna et al., 2024; Khoo-Lattimore et al., 2019; Konieczna, Trybuś-Borowiecka, 2025) and enable experiences unattainable in the physical world (Koohang et al., 2023). Research on the impact of smart tourism technologies on tourist experiences confirms that these technologies significantly contribute to shaping intense emotions and immersive experiences during travel, thereby influencing overall tourist satisfaction (Buonincontri, Micera, 2016). Studies show that smart tourism technologies enhance connectivity, engagement, personalization, and co-creation (Buonincontri, Micera, 2016; Liberato et al., 2018).

The implementation of innovations is particularly visible in the accommodation sector, theme parks and leisure facilities (Krizaj et al., 2012; Booyens, Rogerson, 2016; Panfiluk, 2021). It should be emphasised that, from the tourist perspective, leisure services are optional, and often luxury goods (Divisekera, Nguyen, 2018) thus, only a high level of creativity and innovation can attract customer interest and loyalty. According to Pires (2020), technological innovations in hotels are introduced in guest service processes, including automation/self-service technologies (SST), radio frequency identification (RFID) and intelligent agent technologies (IAT). Rooms are equipped with features such as music systems, video game consoles and satellite TV. Such differentiation and novelty influence new experiences and memories (Elshaer, Marzouk, 2024). Theme parks introduce diverse scenography, decorations and staging inspired by history, nature and fantasy worlds, building atmosphere and intensifying tourist experiences and emotions (Chybalska, 2008)). Cultural facilities, particularly museums, personalize visitor experiences, using text, sound, still and moving images, AR, VR, MR and AI technologies to enhance interactivity, understanding of exhibits and access to additional information (Kasperska, 2014; Kap, 2016; Sawczuk, 2019).

2.2. Generation Z – Consumption Trends in Tourism Services

Generation Z, commonly referred to as “digital natives” Pichler et al. (2021), comprises individuals born between 1995 and 2010 (Su et al., 2019). They are characterized by traits such as impatience, demand for instant delivery, individualism, autonomy, high expectations, and materialism. Their consumption values center around the pursuit of unique, limitless, and ethical products Francis et al. (2018), while their consumer behavior is shaped by sensory, emotional and social experiences, which positively increases their acceptance of novelty (Kim et al., 2020; Stone, Sthapit, 2024).

For Generation Z, travel represents primarily a form of leisure and relaxation, as well as an opportunity to gain new experiences and engage with the culture of the destination (Haddouche, Salomone, 2018; Pricope Vancia et al., 2023). Tourists belonging to this cohort seek authentic, aesthetically appealing and environmentally friendly destinations promoting active leisure and direct contact with nature (Stylos et al., 2021; Pricope Vancia et al., 2023). Their travel choices are increasingly shaped by the desire for emotional and aesthetic

experiences, aligned with the experience-driven travel trend, in which ambience, uniqueness and atmosphere outweigh price or transport accessibility (Kim et al., 2020; Zhang et al., 2025). Accordingly, destination choice is influenced by the attractiveness and diversity of tourism attractions, the availability of services (food, entertainment, recreation), accommodation, and the friendliness and helpfulness of the local community (Basa et al., 2023). They choose both natural landscapes and urban recreational areas. Local distinctiveness and regional authenticity remain critical factors reinforcing the perceived authenticity of the experience (European Travel Commission, 2020). Social media visibility also plays a key role; the presence of “Instagram-worthy locations” is a significant criterion in destination choice, as young travellers willingly share travel photos and videos (Stylos et al., 2021).

Generation Z more frequently engages in active tourism, allowing for nature-based discovery, interaction with local culture and participation in commercial mass culture (Robinson, Schänzel, 2019). This cohort demonstrates openness to innovation and novel travel forms (Haddouche, Salomone, 2018; Robinson, Schänzel, 2019; Kettera, 2021) and emphasises personalised experiences, enabling the creation of individual travel scenarios tailored to personal preferences (Kim et al., 2020; Thangavel et al., 2022). Consequently, they reject traditional organized travel forms in favor of travelling with friends or family (Nemec Rudež, 2023). They prefer shorter trips of 2-3 days but taken more frequently than once a year (Pricope Vancia et al., 2023; Basa et al., 2023).

Travel intentions and destination choices among Generation Z are strongly driven by user-generated content (UGC) and short-form video content (Zhou et al., 2023). They also make use of travel websites, search engines and booking platforms (Stepaniuk, Misiewicz, 2025), highlighting the pivotal role of social media in decision-making processes. Moreover, they rely on recommendations from friends and acquaintances and consult online reviews and ratings of tourism service providers (Nemec Rudež, 2023; Basa et al., 2023; Pricope Vancia et al., 2023). Only one-tenth of Generation Z leaves travel-information searching to others (Nemec Rudež, 2023). However, this group trusts friends and family more than information from websites, indicating cautiousness in travel decision-making (Monaco, 2018).

Based on the above, the following hypotheses are proposed for Generation Z residing in Central and Eastern Europe: H1: they are active travelers, travelling more than once a year, predominantly with friends; H2: they travel primarily for leisure rather than educational purposes; H3: natural and cultural assets are decisive factors in destination choice; H4: destination choice is based on information obtained from social media.

2.3. The Role of Technological Innovations in Generation Z’s Tourist Travel

Studies indicate that Generation Z most frequently uses intuitive and functional smart technologies, such as mobile applications, cashless payments, flight search engines and booking platforms (Ratna et al., 2024; Zhang et al., 2025). Between 87% and 95% of young tourists use smart technologies at the planning, booking and travel stages, strengthening their sense of

control and autonomy (Konieczna, Trybuś-Borowiecka, 2025; Zhou et al., 2023). In contrast, significantly lower usage is observed for advanced technologies such as AI, VR, MR and blockchain. Experimental research demonstrates that approximately 68% of respondents use AI-based tools (chatbots, recommendation systems), while 41% have experienced metaverse-type interactions (Zhang et al., 2025). VR is attracting growing interest—participants report positive emotional reactions and increased travel intentions after immersive virtual experiences (Henríquez-Jara et al., 2025). However, active VR/AR use remains below 15% (Yung, Khoo-Lattimore, 2019). Blockchain adoption is marginal—around 61% of hotels are testing or planning blockchain applications, mainly in payment and guest data verification (Chen et al., 2024). Tourists' actual use remains low, although willingness to adopt trust-enhancing technologies is high (Ratna et al., 2024).

Despite expecting broad access to new technologies and devices providing autonomy, speed and convenience (Priporas et al., 2017; Walters et al., 2021; Zhang et al., 2025) Generation Z is not fully aware of the real potential of advanced technological solutions (Buhalis et al., 2023; Kotler et al., 2021). As noted by Kotler et al. (2021), digitalization in this group occurs mainly at a surface rather than transformational level. New tools are helpful at the planning stage but do not replace human interaction or sensory experience in the real world of tourism (Pricope Vancia et al., 2023).

3. Materials and Methods

In this study, the research methodology was developed on the basis of an identified research gap arising from the current state of knowledge presented in the literature. An analysis of existing publications revealed a limited scope of research concerning Generation Z, indicating the need for a deeper exploration of this topic. Previous authors emphasize the insufficient recognition of the tourism interests of Generation Z, including innovations involving advanced technologies, and highlight the need for further empirical and theoretical research. In response to these recommendations, and to address the identified gap, methodological assumptions enabling a comprehensive examination of the research problem were adopted.

To collect empirical data, a survey method was applied using a CAWI questionnaire, following the principles of the Tailored Design Method (TDM) (Dillman et al., 2014). This method enables the identification of the existing situation in relation to the research objective. The questionnaire was divided into three sections. The first section focused on examining tourism activity and travel purposes. The second part investigated tourists' expectations. The third section consisted of demographic questions. The questionnaire contained semi-open questions with an extended set of qualitative response options. Respondents were allowed to select up to three answers.

The primary research was conducted between April and June 2023 using CAWI techniques and social media platforms. In total, 385 respondents participated in the study, including 185 Generation Z tourists.

Among the respondents, 51% were women and 46% men, with secondary (63%) and tertiary (20%) education, which corresponds to the age of the participants (18-28 years), some of whom were still studying. Most respondents lived in cities with between 151,000 and 500,000 inhabitants (49%), while 16% lived in rural areas and 9% in smaller towns. This structure reflects the demographic profile of young Polish representatives of Generation Z. To analyze the data, the percentage distribution of responses and comparisons between groups based on travel frequency were applied. In this research, a GenAI tool was used during the analysis and conclusion-drawing stage. The obtained material was checked for substantive correctness, i.e., the accuracy of the content, the concepts used, and its alignment with the research objectives. The material was then verified for consistency with the research results, discrepancies and repetitions were removed, the interpretation was refined, and the text was supplemented. The material, which underwent verification and validation, underwent final editing and adaptation to academic style. As a result of the applied procedures, the final interpretation of the results, the formulation of theoretical implications, and practical conclusions constitute the author's original contribution.

4. Results

4.1. Travel Preferences among Generation Z

The research findings allow for the identification of tourism activity, travel motivations and goals, and the significance of innovation in tourist travel. The results were subjected to quantitative analysis.

Most respondents are active travelers. Most travel domestically 2-3 times per year (46%), while 62% travel abroad—usually once a year (34%) (table 1).

Table 1.
Frequency of travel

Travel frequency	Travel	
	abroad	domestically
more than three times a year	10%	17%
two or three times a year	18%	46%
once a year	34%	30%
don't travel at all	38%	6%

Source: own study based on research.

Respondents prefer travelling with friends; every third representative of Generation Z also travels independently, and one in five declares travelling with a partner or children (Figure 1). The results confirm Hypothesis 1: representatives of Generation Z are active travelers who travel more than once a year, predominantly in the company of friends.

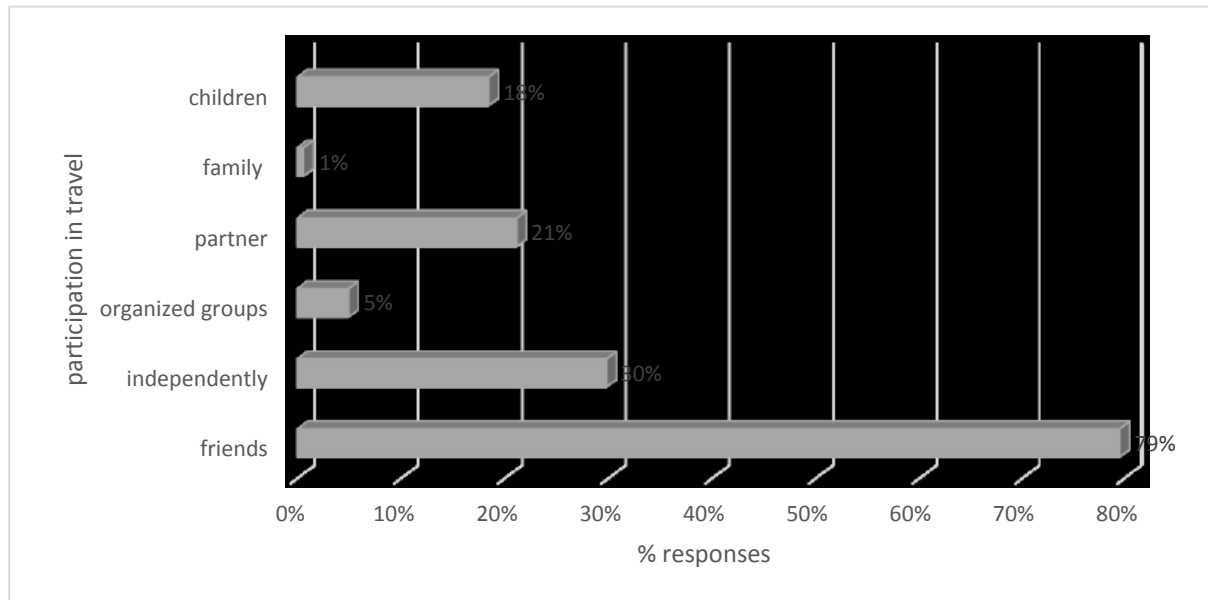


Figure 1. Forms of participation in travel.

Source: own based on research.

Respondents prefer leisure-oriented travel (76%), followed by educational/sightseeing trips (55%), entertainment travel (45%) and recreational trips (46%). Visits to family and friends constitute a supplementary motive (38%). Accordingly, the results confirm Hypothesis 2: representatives of Generation Z travel more frequently for leisure purposes than for cognitive or educational purposes.

Generation Z prefers destinations with favorable climates (69%), characterized by a high number of sunny and rain-free days. Natural and cultural sites, as well as recreational facilities and cultural events, are equally attractive to them. Price (36%) plays a secondary role – young tourists are willing to pay more for authentic and meaningful experiences. For some respondents, unique trails and landmarks (25%) and recreational opportunities (10%) also held importance – figure 2.

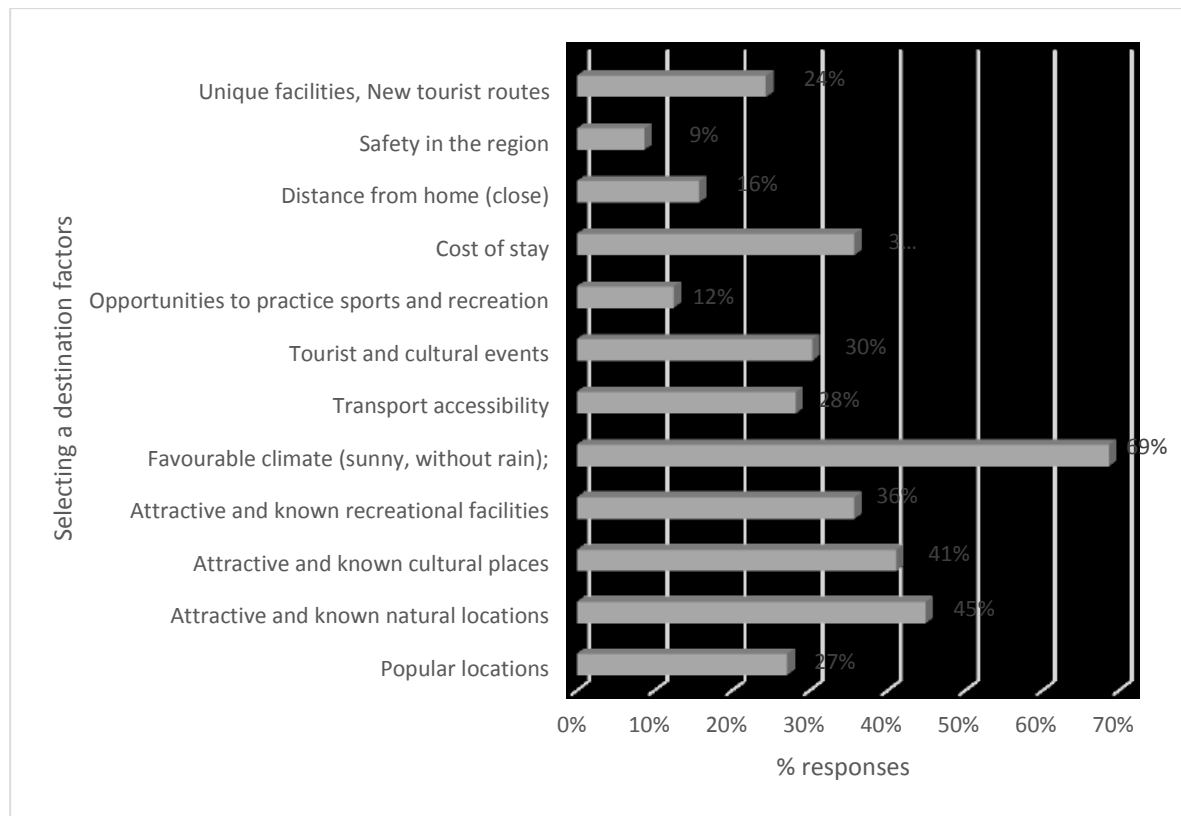


Figure 2. Destination selection factors.

Source: own based on research.

Respondents favor less crowded, authentic locations offering easy access and a pleasant climate, reinforcing their need to balance relaxation, experience and travel comfort. Therefore, Hypothesis 3 is not supported by the findings. The choice of destination is predominantly determined by sunny and rain-free weather conditions conducive to leisure, rather than by natural and cultural assets.

Online advertising (72%) and social media (65%) constitute the primary sources of tourism information for respondents, while recommendations from friends also play an important role (33%). Only a small proportion of respondents use traditional media (television – 16%, radio – 12%). Tourist information centers, books and conferences likewise hold limited importance – table 2.

Table 2.
Sources of tourist information

Source of information	Activity of respondents
Advertising on the Internet	72%
Social media (e.g. Facebook, Instagram, TikTok)	65%
Specialist web services	14%
Friends	33%
Radio advertising	12%
Advertising on television	16%
Scientific books	6%
Magazines	5%
Conferences	9%

Cont. table 2.

By telephone, e.g. information center, hotel accommodation service	6%
Video blogs	14%
Documentary/scientific films	8%
QR codes in tourist regions	3%
Tourist information point	3%
Guide in the region	2%
other	1%

Source: own based on research.

The results confirm the dominant role of digital channels in communicating with young tourists and indicate the need to tailor promotional activities to the online environment, which is consistent with Hypothesis 4.

4.2. Engagement with Innovative Solutions in the Course of Travel

The analysis of Generation Z's interest in the introduction of modern solutions in hotel facilities shows that the greatest interest lies in the introduction of IT technologies to guest services (use of applications), such as check-in, check-out and hotel door opening (58%), and the use of modern, innovative solutions in the facilities, contributing to raising the quality of service (56%) (Table 3). This indicates the increasing role of technology used in customer service and the expectation of a high quality of service. Complementary hotel infrastructure: swimming pools, saunas, car parks, SPA and high quality of hotel service staff are important factors influencing customer satisfaction, although they are not the most important elements determining satisfaction. Although other factors such as the fancy/unique design and internal solutions within a facility (e.g. hotel on wheels, hotel in the tree), and leisure animation offer may attract the attention of customers, they are not the key factors influencing guest satisfaction. It is also worth noting the limited importance of the use of robots in customer service. In summary, a hotel that implements smart technology, solutions to provide quality guest service and to deliver a positive guest experience through apps can achieve higher customer satisfaction and better business results.

Table 3.

Level of interest in innovative solutions in hotels

Specification	Structure
The facility uses modern, innovative solutions to enhance the quality of the service	56%
Use of applications in guest services (check-in, check-out opening hotel doors)	58%
Complementary hotel infrastructure: swimming pools, saunas, car parks, spa	37%
Fancy/unique design and internal solutions of the facility (e.g. hotel on wheels, hotel in a tree)	19%
Leisure time animation offer	14%
High quality service by hotel staff	25%
Robots serving customers	15%

Source: own based on research.

An analysis of Generation Z's expectations regarding the use of modern solutions in a recreational facility (Table 4) allows us to conclude that the greatest interest is aroused by new types of facilities that do not exist anywhere (59%), solutions for unusual ways of moving

around the facility (e.g. unmanned train, etc.) (45%) and facilities equipped with modern technological solutions (e.g. slides, with virtual reality technology) (44%). These solutions are a very attractive and desirable addition to a leisure facility's offer by the representatives of Generation Z, significantly increasing the attractiveness of leisure by those seeking new and unique experiences. Intelligent management systems and smart equipment rentals can improve the efficiency and comfort of the guest experience, which can affect guest satisfaction. A smart virtual personal trainer also has a role to play, although it is not the most important factor in determining guest satisfaction

In conclusion, a new type of leisure facility can arouse the interest of tourists using unique and innovative solutions, including technological solutions, which will allow for an unusual experience, consequently contributing to the satisfaction of visitors and business success.

Table 4.

Level of interest in innovative solutions in recreational facility

Specification	Structure
A new type of object not found anywhere else	59%
Unusual way of getting around the facility (e.g. unmanned queue, etc.).	45%
Equipment using modern technological solutions (e.g. slides with virtual reality technology)	44%
Equipment with intelligent management systems	30%
Smart equipment rental	29%
Intelligent virtual coach (personal)	13%
other	2%

Source: own based on research.

The survey concerning the factors influencing interest in the museum offer (Table 5) carried out among Generation Z representatives indicates that the museum offer should include an interesting new exhibition (53%). Moreover, respondents believe that interest in a museum's offer is determined by the cultural value of the museum (39%) as well as the interest of potential visitors (34%). The value of the offer is increased by modern, innovative solutions (e.g. holograms, virtual books), unconventional way of moving around the object (e.g. stereoscopic 3D glasses) (38%), or the use of e.g. VR technology and interactive exhibitions. These factors suggest that Generation Z is attracted to fresh and intriguing content. From the point of view of the use of modern technology solutions such as 3D stereoscopic glasses, VR technology, and interactive exhibitions are indicated as complementary elements and only by a few respondents, suggesting that they may still be considered experimental solutions. This means that Generation Z's interaction with information technology is only superficial, mostly referring to the use of devices to enhance their activities, with little reference to enhancing experiences and emotions. It should also be pointed out that offers in the form of virtual changing rooms and escape rooms with historical themes are less popular compared to other solutions and offers, suggesting that these types of attractions may be more niche and not of interest to the majority.

Table 5.
Level of interest in the museum offer

Specification	Structure
Interesting new exhibition at the museum	53%
Cultural value	39%
Virtual dressing room (e.g. clothing from different eras)	10%
Escape-room with a historical theme	22%
The facility uses modern, innovative solutions (e.g. holograms, virtual books)	38%
Virtual museums (e.g. VR technology)	6%
Unconventional way of moving around the site (e.g. 3D stereoscopic glasses)	24%
Interactive exhibitions	18%
Interests	34%
Other	1%

Source: authors' own elaboration based on the conducted research.

In summary, the museum's offers should be geared towards innovative exhibitions of high cultural value. It is also important to consider the diverse preferences and interests of visitors, so that the offers should also cater to niche interests. It is important for museums to build their offers based on modern technological solutions. As the results of the study indicate, this will allow entrepreneurs to create innovative offers that are ahead of mass needs and compete on the tourism market.

5. Discussion and Conclusions

Representatives of Generation Z residing in a Central European country prefer leisure-oriented travel that also incorporates cognitive, entertainment and recreational elements. The vast majority of Generation Z favours active outdoor recreation, as evidenced by their preference for regions with a high number of sunny and rain-free days. In addition, they are attracted by natural and cultural sites as well as recreational facilities. Novelty and uniqueness of a destination also generate interest. These findings are consistent with studies by Basa et al. (2023) and Akgış İlhan et al. (2022) who indicate that Generation Z is interested in both biotic and abiotic landscapes.

Most respondents prefer destinations that meet their expectations in terms of attractiveness and quality, as seen in their willingness to incur higher travel costs, although price is not the decisive factor. One in four respondents pays attention to unique attractions and new tourism trails, whereas one in ten values sports and recreational opportunities at the destination. Although destination popularity is among the factors considered by one in four tourists, it is not the most important element for Generation Z, who appear to favour less crowded and more authentic locations.

The dominant information sources used by Generation Z when searching for tourism destinations are online channels, which aligns with findings from previous studies (Kim et al., 2020; Monaco, 2018; Setiawan et al., 2018; Nemec Rudež, 2023; Orea-Giner, Fusté-Forné,

2023). The most influential media are online advertisements, social media platforms and peer reviews. This result is consistent with the findings of Monaco (2018), Khare et al. (2020), Ahani et al. (2019), Nemec Rudež (2023), Orea-Giner, Fusté-Forné (2023), Basa et al. (2023) and Vancia et al. (2023), Pricope Vancia et al. (2023). A significant role of specialized tourism platforms was not confirmed—they serve only as supplementary sources of information, which corresponds with the findings of Basa et al. (2023). In addition, video blogs appear to be of limited importance. This result differs from the conclusions of Pop et al. (2022), Orea-Giner, Fusté-Forné, (2023), Pricope Vancia et al. (2023) and Orea-Giner, Fusté-Forné (2023), who point to a strong influence of social-media influencers as a source of travel information and inspiration (Pricope Vancia et al., 2023).

Within the destination, respondents seek new, attractive facilities offering distinctive solutions and innovative attractions that may significantly enhance the tourism experience. This finding is consistent with Stylos et al. (2021) who emphasise that the motivation for travel among Generation Z is to visit distinctive and original places that evoke emotions and highlight the uniqueness of the tourism experience. Basa et al. (2023) similarly confirms that destination choice is driven by the potential for positive, high-value experiences, which in turn foster loyalty behaviours (Basa et al. 2023).

In holiday packages, respondents show a preference for solutions that facilitate their stay, based on IT technologies and modern, innovative features within the property that improve service quality. The strongest interest is generated by new types of accommodation facilities with unique, modern and unprecedented solutions that significantly enhance the attractiveness of leisure experiences for travellers seeking novelty and emotional stimulation.

These results are consistent with Haddouche & Salomone (2018), Robinson, Schänzel (2019) and Ketter (2021), who demonstrate that Generation Z travellers are highly open to novelty and enjoy co-creating personalised tourism experiences (Robinson, Schänzel, 2019). As Priporas et al. (2017) argue, this cohort expects broad access to diverse electronic devices and digital processes, enabling greater autonomy and faster transactions. These findings also align with Kim et al. (2020), Thangavel et al. (2022), who note that Generation Z values customized tourism offerings tailored to their individual needs and preferences, as well as with Akgış İlhan et al., (2022) , who show that Generation Z selects forms of tourism that deliver highly valued, unique experiences.

Respondents also expressed diverse expectations regarding additional personalized solutions aligned with their interests, enabling them to experience unique moments. Although these expectations were mentioned by a smaller share of participants, they included services and products employing advanced technologies such as 3D stereoscopic glasses, VR technology, interactive exhibitions, robots, virtual fitting rooms, and smart virtual personal trainers. This suggests that such solutions may still be perceived as experimental. This result may support Buhalis & Karatay (2022), Kotler et al. (2021) argument that “digitalization occurs mainly at a surface level, and not yet at a transformative level”, as most technological

engagement concerns tools facilitating operational activities rather than enhancing emotional experiences. Similar findings were reported by Buhalis et al. (2022) and Pricope Vancia et al., (2023) who observed that Generation Z is not yet fully aware of the potential applications of advanced technologies, particularly virtual reality, in tourism services (Pricope Vancia et al., 2023).

The data obtained allow for the identification of several common features that influence Generation Z's interest in tourism offerings and contribute to satisfaction with the tourism destination experience.

Generation Z is particularly attracted to:

- novelty and innovation: solutions that are original and unconventional, making a stay more engaging and interesting,
- uniqueness: tourism facilities offering something unavailable elsewhere, serving as distinctive travel motivations,
- interactivity: experiences that actively engage visitors rather than positioning them as passive observers,
- technology: the use of modern technologies such as mobile applications, virtual reality or smart management systems, enhancing convenience and providing new experiences,
- personalization: solutions aligned with guests' interests and preferences, increasing satisfaction and engagement during the stay.

Theoretical and Practical Implications and Future Research Directions

This study contributes to the growing body of research on Generation Z's tourism behavior by identifying the differentiation in their attitudes toward immersive and non-immersive innovations and by integrating these insights into the broader framework of innovation adoption in tourism. The findings extend existing theoretical discussions on the role of technological advancement in shaping contemporary travel experiences, confirming that innovation acceptance among young tourists depends not only on technological sophistication but also on perceived usefulness, simplicity, and emotional value. An important direction for the development of product innovations is their considerable diversity, based on niche tourist preferences. This will allow personalization of tourism offers and accessibility to diverse tourist segments.

From a practical perspective the research results provide clear guidance on adapting the tourism offer to the needs and expectations of Generation Z representatives living in Central Europe. The preferences identified for this group concern both the factors determining destination choice and expectations regarding accommodation services, recreational facilities, and cultural institutions. This allows for the formulation of practical recommendations for entrepreneurs in the tourism sector.

In the area of accommodation services, research indicates that young tourists value technological solutions that improve their stay and enhance the quality of service the most. The most popular are self-service management applications (check-in, check-out, door opening), as well as modern technologies used to improve comfort and service flow. Therefore, it is proposed that the following solutions be included in their development strategies: implementing digital operational technologies, especially mobile applications for guest services, using innovative hospitality solutions that enhance convenience and personalization of services, and creating distinguishing features of the property (design, unusual forms of accommodation) as an additional factor in building attractiveness.

Regarding recreational facilities, Generation Z shows a clear interest in a unique, experience-based offering. The most excellent attention is drawn to new types of objects, unusual ways of moving around the area, and attractions utilizing immersive technologies. Therefore, it can be concluded that the directions of change should aim towards the realization of: unique facilities and attractions ("one of a kind") that cannot be found elsewhere, the implementation of unconventional methods of transportation (e.g., autonomous trains, themed transport), the integration of VR/AR technology in recreational devices, including motion attractions, the introduction of intelligent facility management systems and smart equipment rentals, increasing user comfort, offering interactive, partially personalized forms of recreation.

In the case of a museum's offerings, the substantive content and the novelty of its exhibitions are key. Technologies play a supplementary role – they increase attractiveness, but they are not a key motivator for visits. Therefore, the museum's offerings should include: regular creation of new, interesting exhibitions of high cultural value; the use of technology (holograms, virtual books, 3D stereoscopy) as tools to support the narrative; the development of interactive exhibition elements that increase visitor engagement; offering attractions aimed at niche interest groups (e.g., themed escape rooms) as a supplement to the main offerings; maintaining a balance between modern tools and the authenticity of the content, which is particularly important to young tourists.

Additionally, the results clearly indicate the dominant role of digital media in the information gathering and travel decision-making process of Generation Z. Therefore, it is proposed: conducting marketing activities online (social media, advertising campaigns, video content, Instagram, TikTok, or YouTube), taking into account the authenticity of the message and peer recommendations as key elements influencing this group's decisions.

In summary, tourism sector entrepreneurs who implement intuitive operational technologies, offer unique and engaging experiences, and base their communication on digital channels have the most excellent chance of effectively reaching Generation Z. Integrating modern solutions with authenticity and high-quality services can be a competitive advantage in the rapidly developing tourism services market.

Another research direction should be the analysis of barriers limiting the adoption of immersive technologies (VR, AR, MR) by Generation Z. It is necessary to investigate why the group known as "digital natives" only use advanced tourism technologies superficially and which factors – functional, emotional, and cognitive – condition their scepticism towards immersive solutions.

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HAZARD IDENTIFICATION STRATEGY REGARDING PPE IN CIVIL DEFENCE TRAINING AND MANAGEMENT

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Purpose: the impose of the 2024 Act on Civil Protection and Civil Defence into the Polish legal system, along with the regulation concerning civil protection training programmes, has imposed on civil protection entities the obligation to conduct training aimed at building social resilience. However, a significant gap has been identified: there are no guidelines specifying the thematic scope of training on personal protective equipment (PPE), no indications of the threats against which such equipment should provide protection, and no strategy for selecting PPE appropriate to specific threats within the civil protection framework. The main objective of the article was to present a strategy for identifying threats in civil protection that personal protective equipment is intended to mitigate.

Design/methodology/approach: the research process employed content analysis of source documents, including the Act and the regulation defining the framework for civil protection training programmes. In addition, a systemic interpretation was applied to examine threats and the personal protective equipment that should be used within the scope of civil protection and civil defence.

Findings: the analysis enabled the identification of three main categories of threats against which personal protective equipment should provide protection within crisis response. This categorisation made it possible to correlate these threats with the assumptions of the crisis management system and, subsequently, to specify individual threats in relation to the population. As a result of content analysis the article presents the algorithm of planning and managing PPE field in trainings and physical hazard identification.

Research limitations/implications: The main limitation of the research is the lack of empirical data and the absence of detailed training programmes, which results from the early stage of implementing the new legal system and the limited literature on the use and management of personal protective equipment within civil protection.

Practical implications: the added value of this study lies in presenting an innovative strategy for identifying threats and selecting PPE, which fills a gap in current crisis management plans and enables precise definition of training content for the public. Future research should involve empirical analysis of the scope of PPE trainings and review of real hazard identification strategies applied into personal safety during assuring civil protection activities.

Social implications: introducing indicated strategy of identifying real hazards which can occur real impact as accidents or diseases will raise the ability of proper behavior either in emergency reaction or during every day activities. In its sense, the strategy implementation contributes directly to the enhancement of national safety culture.

Originality/value: this paper is the first academic studies which involve interdisciplinary way of identifying hazards which may cause an accident or diseases during civil protection planning or crisis management which include real hazards aimed to human beings with innovative hybrid-matrix of identifying hazards in Civil Defence.

Keywords: PPE, civil defense, civil protection, hazard identification.

Category of the paper: action research, view point.

1. Introduction

Civil protection is a system composed of public administration authorities responsible for ensuring the safety of the population by protecting human life and health, property (including animals), infrastructure essential for basic needs, cultural assets, and the environment in situations of threat. These authorities are referred to as civil protection bodies, while the entities performing these tasks are referred to as civil protection entities. The system also includes civil protection resources (Act of 5 December 2024 on Civil Protection and Civil Defence, 2024).

Civil defence comprises the tasks defined in Article 61(a) of the Additional Protocol to the Geneva Conventions of 12 August 1949 relating to the protection of victims of international armed conflicts (Protocol I), drawn up in Geneva on 8 June 1977 (Journal of Laws 1992, item 175; Journal of Laws 2015, item 1056). Its purpose is to protect the civilian population from threats arising from military actions and their consequences (Journal of Laws 1992, item 175; Journal of Laws 2015, item 1056).

The Polish legal system explicitly separated these two concepts with the preparation and entry into force of the Act on Civil Protection and Civil Defence. Beyond introducing new definitions, the Act implemented a fundamental change in building social resilience to extraordinary situations. This change consists of mandatory training delivered at intervals defined in the Act and in the implementing regulation on training programmes (Regulation of the Minister of the Interior and Administration of 6 February 2025 on training programmes in civil protection and civil defence and requirements for training providers, 2025). The programmes also include the topic of personal protective equipment—from training for county-level authorities to training for the general population.

However, with regard to training on the use of personal protective equipment within civil protection, there are currently no guidelines on what topics should be covered, nor what types of equipment should be used for specific categories of threats. This gap creates a need for a strategy to identify the detailed threats against which particular types of PPE should provide protection. There are also no guidelines regarding the thematic scope of the training module devoted to PPE.

Given this identified research gap, the following research questions were formulated:

QR1: how should training on personal protective equipment be understood at different levels of civil protection preparedness?

QR2: against which threats is personal protective equipment intended to provide protection?

QR3: how are current threats within civil protection identified?

These research questions enabled an analysis of the assumptions underlying civil protection training, particularly within the thematic blocks concerning personal protective equipment. The study also identified the basic categories of threats against which PPE is intended to protect and proposed a strategy for their detailed identification. This strategy can be implemented in the development of training content and may expand existing crisis management plans by integrating issues of individual protection for system participants.

This study represents an entirely new approach to threat identification within the Polish system of building social resilience. In the context of civil protection and civil defence, such an approach has not been previously applied. It also introduces an interdisciplinary perspective to the strategy for classifying threats related to PPE, which must be incorporated into civil protection training.

2. Theoretical and legal framework

In accordance with Chapter 6 of the Act on Civil Protection and Civil Defence, the legislator introduced an obligation to organise training aimed at improving qualifications in the field of civil protection and civil defence in offices serving civil protection authorities, as well as in other offices, organisational units of local government, and auxiliary units of municipalities (op. cit.). An analysis of the Act in light of the training programmes shows that it distinguishes between civil defence authorities and civil defence entities (ibid.).

With regard to the thematic scope related to personal protective equipment, civil protection authorities include county governors (starosts), city mayors, town mayors, and commune heads. Civil protection entities, on the other hand, consist of institutions, associations, and services listed in Article 17(1) of the Act (ibid.). It is crucial to emphasise who will physically carry out the tasks imposed on civil protection entities by these authorities. Within these entities, depending on the legal basis for task implementation, employees, contractors, officers, and volunteers - hereafter collectively referred to as employees - are engaged. This is particularly important for the execution of civil protection and civil defence tasks related to personal protective equipment, as it is these individuals who will be deployed to mitigate extraordinary events. They must therefore be provided with appropriate personal protective equipment.

The structure of the regulation defines the training programmes and the requirements for entities authorised to deliver them. The programmes include nine training groups:

- 1) ministers, secretaries of state, undersecretaries of state, and heads of central offices,
- 2) provincial governors and regional marshals,
- 3) county governors (starosts),
- 4) commune heads, town mayors, and city mayors,
- 5) staff in offices serving civil protection authorities and in other local government offices, organisational units, and municipal auxiliary bodies,
- 6) persons with civil defence mobilisation assignments,
- 7) personnel of civil protection entities,
- 8) members of associations and business operators,
- 9) the general population (ibid.).

The structure of the training programmes defines:

- 1) the training objective,
- 2) the training participants,
- 3) the organisational form of the training,
- 4) the thematic scope,
- 5) the method of verifying whether the training objective has been achieved (ibid.)

Particular attention should be paid to the thematic scope of training for county governors, commune heads, town and city mayors, staff of offices serving civil protection authorities, employees of other local government units and auxiliary bodies, personnel of civil protection entities, members of associations and business operators, and - more broadly - the general population. In all these programmes, the thematic block on personal protective equipment is mandatory.

The Act also provides a legal definition of a threat in the context of civil protection and civil defence. According to this definition, a threat is a situation that negatively affects the safety of life and health, property, cultural assets, or the environment, or that limits the functioning of public administration bodies or infrastructure essential to civil protection and civil defence tasks (ibid.). Categories of threats are further detailed in Article 4(4) (f-h), which outlines tasks within civil protection.

The general categories of threats listed in this legal provision, which are particularly important for designing a threat identification strategy and, consequently, for defining the PPE training block, include:

- 1) chemical, biological, radiological, and nuclear threats, including the mitigation of their consequences,
- 2) threats caused by natural forces, including those resulting from climate change,
- 3) threats associated with the presence of wild animals in inhabited areas (ibid.).

It is also necessary to refer to other obligations imposed on public administration within the Polish crisis management system, of which civil protection has become an integral part. Crisis management regulations require the development of a threat assessment within the main crisis management plan (Smoleński, 2023). The main plan includes guidelines from the National Crisis Management Plan (KPZK, 2025), which serves as a planning document for lower administrative levels. Part A of the NCMP contains a threat assessment essential for crisis management planning (KPZK, 2025).

According to the NCMP, the Polish crisis management system identifies threats that are significant from the perspective of state functioning. Importantly for the training dimension, survey responses regarding the educational value of crisis management plans indicate that more than 77% of participants viewed these plans as educationally valuable (Smoleński, 2021). Over 53% recognised them as potentially useful educational material, while nearly 24% considered them highly valuable educational material (Smoleński, 2024).

In the context of occupational safety and health, threats are categorised into specific types and detailed in legal acts and guidelines, both in terms of accident prevention and health hazards (Koradecka, 2008). Moreover, legal regulations concerning occupational safety make it possible to identify specific threats and corresponding categories of personal protective equipment (Pisarczuk, 2023). In this context, a threat is defined as a source capable of causing injury or health impairment (PN-ISO 45001).

Threat identification can also be carried out at a more detailed level across multiple aspects. However, the most universal approach involves classifying threats using criteria such as: source of origin, location, involvement of military factors, current relevance, available knowledge, time, frequency, intensity, scope, symptoms, number of contributing factors, and degree and scale of destruction (Kaczmarczyk, 2014).

Regarding the thematic block on personal protective equipment, PPE is defined as equipment designed and manufactured to be worn or held by a person to protect against one or more threats to their health or safety (Stefko, 2022). Threats in the context of PPE use are typically categorised as physical, chemical, and biological (Pisarczuk, 2023).

The literature includes studies conducted in Polish conditions on the use of personal protective equipment in particular crisis response situations. These studies concern CBRN (chemical, biological, radiological, nuclear) threats. The general classification of PPE includes respiratory protective devices - such as self-contained breathing apparatus (SCBA) and air-purifying apparatus (APA) - as well as dermal protective equipment (Bodurtha, Dickson, 2016). Research conducted in Poland examined the use of specific PPE categories according to designated hazard zones (hot, warm, and cold zones) during CBRN incidents, including responses by the State Fire Service (Gikiewicz, Bralewska, 2021) and Medical Rescue Services (Trzos, Jurowski, 2019).

Civilian response studies identified specific CBRN threats such as sarin, ammonia, dirty bombs, and multi-point CBRN attacks (Gikiewicz, Bralewska, 2021), as well as novichok, chlorine, anthrax, botulinum toxin, epidemics, and nuclear accidents (Trzos, Jurowski, 2019). In both cases, the general use of chemical protective suits, breathing apparatus, and full-face masks with filter cartridges was indicated.

Given that existing studies relate only to CBRN-related PPE used by specialised emergency services, the following research hypotheses were formulated for the purposes of this analysis:

- H1:** There is a general division in the appropriate preparation of the population regarding the provision, use, and training in PPE within civil protection.
- H2:** No specific guidelines exist on correlating threats in civil protection with the use of personal protective equipment.
- H3:** The current strategy is based on the crisis management system, which does not address threats in terms of individual protection.

Verification of the above hypotheses will allow for the determination of the coherence level of the current legal and organisational system. Furthermore, it will enable the creation of a dedicated tool (algorithm) facilitating the management of PPE training, which constitutes the practical objective of this study.

3. Research methodology

The research methodology employed was based on two pillars, responding to the reviewers' comments regarding the operationalisation of the process:

- content analysis - the primary method was the content analysis of source documents, primarily the Regulation of the Minister of the Interior and Administration of 2025 and the superior Act on Civil Protection and Civil Defence in connection to environmental health and safety scope of identification proper PPE. The interpretation criteria included identifying defined target groups for PPE training and general scope of indicating proper PPE for defined hazards.
- systemic interpretation - the analyzed provisions of the regulation were placed within the broader context of the state's strategic goals arising from the Act. This method allowed for linking specific requirements with the overarching goals of the system, such as building societal resilience and strategy which should be implemented widely across crisis management field.

The main limitation identified in the research process is the current absence of detailed training programmes within the thematic blocks of the framework curriculum. The training system was launched only this year, which also limits the study due to the lack of empirical

data specifically related to the module on personal protective equipment. Moreover, the absence of literature addressing strategies for selecting personal protective equipment for training purposes and for building social resilience leaves no point of reference in this area.

4. Results

Identifying the research gap made it possible to conduct a systemic analysis of the purpose and content of the Act in relation to the threats for which the training block on personal protective equipment should provide preparation. This analysis draws directly from the content of the Act and points to three general categories of threats:

- 1) CBRN threats,
- 2) natural hazards,
- 3) threats posed by animals.

Subsequently, the assumptions underlying the training objectives were analysed with reference to the groups for which the PPE module is required. These groups include:

- 1) county governors (starosts),
- 2) commune heads, town mayors, and city mayors,
- 3) staff in offices serving civil protection authorities and in other local government offices, organisational units, and auxiliary bodies,
- 4) persons with civil defence mobilisation assignments,
- 5) personnel of civil protection entities (training optional, subject to the decision of the civil protection authority),
- 6) members of associations and business operators (training optional, subject to the decision of the civil protection authority),
- 7) the general population (training optional, subject to the decision of the civil protection authority).

The analysis of the training programme, combined with the roles assigned to these groups, allowed for the identification of the following elements shaping the purpose of the PPE-related training content:

1. for authorities managing civil protection and civil defence tasks, the Act assigns the following duties to county governors and municipal civil protection bodies with regard to ensuring personal protective equipment: directing and coordinating, within the scope of their competencies, creating and maintaining, within the municipality (or county), civil protection resources and infrastructure essential for performing civil protection and civil defence tasks, including water supply infrastructure, providing emergency assistance through civil protection entities, issuing recommendations to civil protection entities regarding the types and quantities of civil protection resources to be maintained (Act on Civil Protection and Civil Defence, 2024).

2. for staff of offices, civil protection entities, associations, business operators, and the general population, the key point is that civil protection entities carry out civil protection and civil defence tasks within the scope of their assigned responsibilities (ibid.).

The integration of OHS standards with Civil Protection hazard identification is necessitated by the legal status of the personnel involved. Since tasks within civil protection entities are performed by employees and volunteers, the rigorous hazard classification systems established in OHS regulations constitute the obligatory baseline for safety. Furthermore, the physiological impact of hazards (e.g. chemical or biological agents) remains constant regardless of whether the context is an industrial accident or a civil protection emergency, mandating the application of standardized PPE categories defined in established safety norms.

Based on comparative and systemic analysis of the threats identified in the new civil protection framework - supported by the established crisis management system, the guidelines of the National Crisis Management Plan (KPZK), and requirements derived from occupational health and safety regulations - the following categories of threats were distinguished. The identification of main categories of hazards derived from analysis of Act on Civil Protection and Civil Defence is presented in Table 1.

Table 1.
Categories of hazards

CBRN	Natural disaster	Animals
Chemical contamination. Biological contamination (epidemic, epizootic, epiphytotic). Radiological contamination. Nuclear hazards (from nuclear attack)	Flood. Drought/heatwave. Strong wind. Severe frost/intense snowfall. Fire	Physical and biological hazards resulting from contact or attack by wild animals (e.g. bites, scratches)

Source: own preparedness.

This combination of systemic analysis and content analysis made it possible to identify detailed, potential threats within the scope of civil protection and civil defence combined with occupational health and safety threats. Detailed characteristics of chemical, biological, and radiological threats mapped to specific civil protection needs are shown in Table 2.

Table 2.
Categories of detailed hazards – CBRN scope

Chemical	Biological	Radiological/Nuclear
Toxic industrial chemicals (per hazardous substances register). Chemical warfare agents. Agricultural processes using pesticides. Transport of hazardous substances. Transport of chemical energy resources. Fire. Explosion.	Epidemic/epiphytotic/epizootic caused by pathogens of infectious diseases (per national infectious disease register; groups III/IV per OHS regulations). Pathogen particles in aerosols, liquids, materials, humans, animals.	Ionizing radiation. Fallout dust

Source: own preparedness.

Table 3 outlines the specific physical hazards associated with natural disasters and their harmful factors.

Table 3.
Categories of detailed hazards – natural disaster scope

Dangerous	Harmfulness
Falling or ejected objects; impact with obstacles; high-pressure streams. Slip-related falls. Falls from height. Static compression of body parts. Abrasion, puncture, cuts, lacerations, entrapment, crushing. Entanglement or capture. High temperature/fire. Low temperature. Electric shock (direct/indirect contact). Static electricity. Injuries due to low visibility. Asphyxiation (oxygen deficiency). Drowning. Explosion. Hazards from high-risk work.	Vibration. Noise. Optical radiation (non-ionizing)

Source: own preparedness.

Hazards related to the presence of animals, including direct attacks and zoonotic diseases, are classified in Table 4.

Table 4.
Categories of detailed hazards – animal scope

Animals	Hazards
Animals listed under OHS regulations for zoological facilities. Other dangerous animals occurring within the jurisdiction.	Bites. Attacks. Pathogenic microorganisms transmitted by insects and animals. Kicks/strikes. Trampling. Venom poisoning.

Source: own preparedness.

Such an analysis makes it possible to plan the training content appropriately within the module concerning the use of personal protective equipment, by linking specific PPE to clearly defined types of threats. It should be noted that the table below also includes specialist equipment due to the nature of certain threats. Furthermore, within civil protection entities assigned particular tasks, specialised workplaces or formations may also be designated. The correlation between identified hazards and the required types of personal protective equipment for specific body parts is presented in Table 5.

Table 5.
PPE and hazards

Hazard	Affected body part and type of PPE
Falling or ejected objects; impact with obstacles; high-pressure streams	Skull: protective helmet. Eyes/face: safety glasses, goggles, face shields. Lower limbs: protective footwear with toecaps, midfoot protection, anti-slip soles.
Slip-related fall	Feet: anti-slip footwear. Skull: protective helmet.
Falls from height	Whole body: fall-protection PPE. Skull: protective helmet.
Vibration	Hands: protective gloves. Feet: anti-vibration footwear.
Static compression of body parts	Knees: kneepads. Feet: safety footwear with toecaps. Hands: compression-resistant gloves.
Abrasion, puncture, cuts, lacerations, entrapment, crushing	Eyes/face: goggles, face shields. Hands: mechanical-protection gloves. Forearms: protective sleeves. Torso/lower limbs: protective apron, gaiters, cut-resistant trousers. Feet: penetration-resistant footwear.
Entanglement or capture	Whole body: protective clothing for moving-parts exposure.
Noise	Hearing: hearing protectors.
High temperature or fire	Head/face: welding helmets/visors, heat-resistant helmets, protective hoods. Torso/lower limbs: protective apron, gaiters. Hands: heat-resistant gloves. Forearms: sleeves. Feet: heat-resistant footwear. Whole body: heat- and flame-protective clothing.
Low temperature	Hands: cold-protective gloves. Feet: cold-protective footwear. Whole body/head: cold-protective clothing.
Electric shock (direct or indirect contact)	Head: insulating helmet. Hands: insulating gloves. Feet: insulating footwear. Whole body: conductive PPE (for qualified personnel up to 800 kV AC / 600 kV DC).
Static electricity	Hands: antistatic gloves. Feet: antistatic or conductive footwear. Whole body: antistatic clothing.
Non-ionizing radiation (incl. sunlight)	Head: caps, helmets. Eyes: safety glasses, goggles, face shields. Skin: UV-protective PPE. Face/hands: skin-protection creams.
Ionizing radiation	Eyes: radiation-protective goggles. Hands: radiation-protective gloves. Torso: X-ray protective aprons/coats/vests/skirts. Head: protective headwear. Body parts: thyroid and gonad protection. Whole body: radiation-protective suits.
Chemical aerosols – solid particles	Respiratory system: particulate-filtering RPE. Hands: chemical-protective gloves, protective cream. Whole body: particulate-protective clothing. Eyes/face: goggles, face shields.
Chemical aerosols – liquid particles	Eyes/face: goggles, face shields. Respiratory system: particulate-filtering RPE. Hands: chemical-protective gloves. Whole body: chemical-protective clothing.

Cont. table 5.

Chemical liquids – immersion, splashes, spraying	Eyes: goggles, face shields. Hands: chemical-protective gloves. Forearms: chemical-protective sleeves. Feet: chemical-protective boots. Whole body: chemical-protective clothing.
Chemical gases and vapours	Respiratory system: gas-filtering RPE. Hands: chemical-protective gloves. Whole body: chemical-protective clothing. Eyes/face: goggles, face shields.
Biological hazards – aerosols (solid/liquid particles)	Respiratory: particulate-filtering RPE. Hands: microorganism-resistant gloves. Whole body/body parts: biological-protective clothing. Eyes/face: goggles, face shields.
Biological hazards – liquids (direct/indirect contact, splashes)	Hands: microorganism-resistant gloves. Whole body/body parts: biological-protective clothing. Eyes/face: goggles, face shields. Forearms: protective sleeves. Feet/lower limbs: boot covers, gaiters.
Biological hazards – persons, animals, materials	Hands: microorganism-resistant gloves. Whole body/body parts: biological-protective clothing. Eyes/face: goggles, face shields.
Low visibility	Whole body: high-visibility PPE.
Asphyxiation (oxygen deficiency)	Respiratory system: isolating breathing apparatus; diving equipment.
Drowning	Whole body: life jacket.

Source: own preparedness based on OHS general Regulation.

Based on the results of the analysis presented in the tables above, a procedural algorithm was developed for planning the training block covering issues related to personal protective equipment. This algorithm is sufficiently universal to be applied not only in designing. The algorithm includes few steps.

Step 1 involves collecting the data necessary for planning the training block, namely determining the training group (managerial level or operational/reactive level). After determining, authorities should hand over proper crisis management plan so that identify proper hazards required for training.

Step 2 consists of identifying the threats indicated in the crisis response plans applicable to the area of responsibility of the civil protection authority.

Step 3 requires translating these threats into threats defined within the framework of civil protection and civil defence, in accordance with Tables 1, 2, 3, and 4.

Step 4 consists of the actual identification of threats affecting individuals, along with determining the personal protective equipment that minimises the risk of injury.

Step 5 involves preparing the appropriate training resources, developing practical training scenarios (for the operational group), or addressing the characteristics of PPE relevant for planning procurement, storage, and maintenance by the civil protection authority (for the managerial group).

Step 6 is the implementation of the training.

To illustrate the algorithm's operational value, a hypothetical scenario can be applied as given:

Step 1 – authorities should contact the training company and determine who is planned to be trained – managerial or operational level. Authorities should hand over updated crisis management plan to company.

Step 2 – training company should analyse a crisis management plan and identify general hazards which base on National Crisis Management Plan (e.g. flood without high risk industry).

Step 3 and 4 – if a flood is identified as a scenario, next step should be consisted of using the matrix indicated in Table 1, 2, 3, 4 and identifying process should be implemented:

Table 6.

PPE related to hazards in Civil Defence. Scenario of hazard: flood (without high-risk industry)

Category of Civil Defense hazards	Category of detailed hazards	PPE
CBRN	Biological – epidemic liquids (direct/indirect contact, splashes, persons, animals, materials)	Hands: microorganism-resistant gloves. Whole body/body parts: biological-protective clothing. Eyes/face: goggles, face shields. Forearms: protective sleeves. Feet/lower limbs: boot covers, gaiters.
Natural disaster	Drowning, Slip-related falls. Abrasion, puncture, cuts. Low temperature. Electric shock (direct/indirect contact). Injuries due to low visibility. Drowning.	Feet: anti-slip footwear. Skull: protective helmet. Whole body: life jacket. Whole body: high-visibility PPE. Hands: cold-protective gloves. Feet: cold-protective footwear. Whole body/head: cold-protective clothing (additionally with waterproof features). Eyes/face: goggles, face shields. Hands: mechanical-protection gloves. Forearms: protective sleeves. Torso/lower limbs: protective apron, gaiters. Feet: penetration-resistant footwear.

Source: own preparedness.

Step 5: practical development of training scenario – how to use specific PPE (operational level) and how to introduce a proper management plan for resources (managerial level). Important note – the resources which would be supposed to use during real situation, should be available for attendees.

Step 6: training implementation according to detailed scenario.

5. Discussion

Developing a strategy for planning the thematic block, based on the results of the systemic and content analyses presented, made it possible to verify the research hypotheses:

H1 was verified by distinguishing two levels that must be considered within the training block on personal protective equipment: the managerial level and the operational (reactive) level. Consequently, the depth of training content must differ significantly between these groups. The managerial level requires knowledge focused on logistics, quantitative planning, and maintenance specifications derived from general obligations included in the Act. It is pointed out distinctly that county governors (starosts), commune heads, town mayors, and city mayors are obliged to create and maintain civil defence resources such as PPE to ensure resource availability. In contrast, the operational level requires basic operational skills related to obligations enacted by the Act, which indicates that executive level is obliged to realise tasks referring to Civil Defence obligations. This differentiation ensures that the strategy is actionable and tailored to the specific roles within the civil protection system. The managerial level is responsible for organising the system that ensures the availability of necessary PPE (civil protection resources), while the operational level is responsible for the correct use of PPE for personal protection. Thus, the analysis provides an answer to **QR1**.

H2 was confirmed through an analysis of the civil protection system, the crisis management system, and occupational health and safety requirements, correlating threats with specific types of personal protective equipment. The Act itself does not specify the types of threats against which PPE is intended to protect. Only by analysing the Act's purpose - building social resilience - and the purpose of the training - preparing the population practically for extraordinary situations - was it possible to identify relevant threats. This allowed the study to address **QR2**.

H3 was verified by examining how the new civil protection system operates alongside the crisis management system. The current approach to threat identification in crisis management is based on the National Crisis Management Plan, which frames threats in terms of public safety and their impact on the functioning of affected areas. The findings of this study made it possible to identify specific types of threats through an interdisciplinary systemic analysis. This approach introduces a new perspective on understanding threats - one that extends beyond the work environment to everyday life and crisis response scenarios.

A crucial aspect of training planning is the need to tailor the training to the current situation in the area where it will be conducted. At this stage of the training process, it is necessary to consider the risk assessment of specific threats within the framework of crisis management and to ensure that the appropriate personal protective equipment is selected and secured for demonstration purposes.

The analysis presented here enables the expansion and enhancement of crisis response plans and civil protection training by providing concrete guidelines for building social resilience. Implementing the proposed threat identification strategy for PPE use will facilitate further research on the evolution of crisis planning, the identification of detailed threats, and the training of participants in the proper application of personal protective equipment.

The innovation of this approach lies in the cross-domain integration of strictly regulated Occupational Health and Safety (OHS) standards with the broadly defined, often general, Civil Defence procedures. Unlike previous classifications which focused solely on industrial safety or strictly military CBRN defence, this strategy creates a hybrid matrix. It applies industrial safety precision (specific PPE regulations) to mass-scale civil protection scenarios, filling the gap where civil operational personnel were previously treated as general population without specific protection standards.

6. Conclusions

The interdisciplinary analysis of the training block on the use of personal protective equipment represents a significant contribution to preparing the population for effective social resilience building.

The key conclusions that can be drawn from the analysis are as follows:

- 1) confirmation of a gap in the guidelines for the PPE training curriculum within the Polish civil protection system, a new issue arising from the implementation of the 2024 Act. Filling this gap by correlating identified threats with specific types of PPE (as presented in the detailed tables) is essential for achieving the overarching goal of building practical social resilience.
- 2) identification and verification of the dual-level approach to PPE preparedness. The managerial level (authorities) must focus on organising and ensuring access to PPE resources (including civil protection resources). The operational level (personnel and the general population) requires concrete knowledge and practical skills for the correct use of PPE for personal protection. Training programmes must clearly reflect and separate these two dimensions.
- 3) the interdisciplinary, systemic analysis (combining civil protection, crisis management, and occupational health and safety) enabled the identification of three main categories of threats-CBRN, natural hazards, and wild animal-related threats - and their subsequent specification. This detailed categorisation is innovative in the Polish system and provides a concrete, recommended foundation for developing the detailed content of the PPE training module.

This analysis has demonstrated the need to expand threat identification strategies within existing management and civil protection systems. Such an expansion should include the detailed identification of accident-related threats and the indication of the types of personal protective equipment required for these threats. This approach enables the proper planning of the training block and enhances public awareness of threats that may arise during crisis response activities.

An additional aspect of the proposed strategy is the development of a procedural algorithm for planning PPE-related training, which is also useful for planning civil protection resources, including PPE. This algorithm helps establish the framework for detailed training content, namely:

- 1) what types of material threats may occur during activities resulting from the events identified in this study,
- 2) what types of personal protective equipment should be used for each specific threat,
- 3) what the conditions of use are for the relevant personal protective equipment,
- 4) how to use specific personal protective equipment in practice.

This study does not close the research area concerning strategies for PPE use and training in civil protection. Further research directions may include: developing a system for selecting specific PPE by civil protection authorities, proposals of detailed training programmes for general trainings in Civil Defence scope, establishing logistical and storage principles for such equipment, and examining how expanding crisis management plans with the proposed approach influences public awareness and the development of practical training content.

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THE USE OF AI IN ACCOUNTING – CASE STUDIES AND PROSPECTS FOR IMPLEMENTATION

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Purpose: The purpose of the study was to assess the level of interest in adopting artificial intelligence (AI) solutions in accounting offices and corporate finance departments, as well as to identify the main barriers and challenges affecting their implementation. The research also aimed to evaluate the current use of AI tools in key accounting processes and to outline future prospects for digital transformation in the accounting profession.

Design/methodology/approach: The research method consisted of conducting a survey among owners and managers of accounting offices and financial departments of companies employing more than 50 employees in the financial department.

Findings: The results of the survey indicate that among small accounting firms, only a small number of owners are considering implementing AI, although they admit that they are already using some tools based on this technology. In larger companies, the percentage of those interested in implementing AI is higher. The most frequently cited key barriers are high implementation costs and lack of sufficient knowledge about the technology.

Research limitations/implications: The study is limited to the Polish market and is based on declarative survey data, which may include subjective bias. The predominance of SMEs in the sample restricts the generalization of results to larger enterprises. Future research should include cross-country comparisons and longitudinal analyses to assess the long-term impact of AI adoption in accounting.

Practical implications: The study results indicate the need to increase awareness and education about artificial intelligence in accounting, which may contribute to greater acceptance of these solutions and their more effective implementation in practice.

Social implications: AI implementation in accounting transforms traditional job roles, emphasizing analytical and advisory skills over routine tasks. Unequal access to advanced technologies may deepen the digital divide between firms. Therefore, developing digital competencies and clear ethical and regulatory frameworks is essential for responsible and inclusive AI integration.

Originality/value: The study's originality and contribution to science is manifested in its empirical analysis of the perception and feasibility of implementing AI in different types of accounting organizations, which enables a better understanding of the dynamics of technological change in the industry.

Keywords: Artificial intelligence (AI), accounting, digitization of finance, process automation.

Category of the paper: Research paper.

JEL Code: M41, C88.

1. Introduction

The rapid development of artificial intelligence (AI) technology in recent years is significantly changing the way various sectors of the economy operate, including accounting and finance. Traditional accounting and financial analysis methods are becoming increasingly automated, which affects the efficiency of decision-making processes, reduces errors and increases the transparency of financial reporting. Increasing digitization and the growing volume of financial data generated by companies require the use of modern analytical tools to enable effective information management. AI is becoming not only a support for accountants, but also a key element in predicting financial trends, detecting anomalies and analyzing risks.

Artificial intelligence in accounting encompasses a wide range of technologies, such as machine learning (ML), natural language processing (NLP) and business process robotics (RPA). In the literature, AI is defined as the ability of computer systems to perform tasks that require human intelligence, such as data analysis, decision-making and forecasting. In the context of accounting, AI is used in accounting process automation, financial fraud detection, predictive financial analysis and auditing.

One of the key issues surrounding the implementation of AI in accounting is its impact on the quality of financial reporting and regulatory compliance. Analytical algorithms can support compliance processes with international accounting standards (IFRS) and tax regulations, but their implementation also raises challenges regarding the interpretability of results, ethics and accountability for decisions based on the recommendations generated.

Modern accounting systems are increasingly using AI solutions to automatically classify transactions, forecast liquidity or assess credit risk. At the same time, there are challenges to implementing these technologies, such as the need to ensure high data quality, legal regulations and ethical issues related to algorithmic decision-making.

The purpose of this article is to analyze selected use cases of AI in accounting and assess the prospects for implementing these technologies in the context of future regulatory and technological changes. The article will analyze specific examples of AI applications in accounting, taking into account their effectiveness and limitations.

The article consists of several sections. The first section will present the existing research on the issue taken up. Next, the methodology of the study and the results from the research will be presented. It will conclude with conclusions on the prospects for further implementation of AI in accounting and recommendations for practitioners and researchers in the field. Taking into account both the benefits and challenges of implementation.

2. Research overview

There has been a noticeable increase in interest in the use of AI in accounting and finance in the academic literature. Empirical studies indicate that the implementation of artificial intelligence technology can lead to a reduction in operating costs and increase the accuracy of financial reporting. An example is the research of B. Prusak and T. Korol who showed that ML algorithms effectively predict the risk of corporate insolvency, which is applied to the credit decisions of financial institutions (Korol, Prusak, 2018). Also, other works that indicate the use of NLP to analyze the content of financial reports most often produce results that demonstrate the high utility of the resulting diagnoses.

Comparative studies of AI implementation in accounting also highlight that companies vary in their level of readiness to implement new technologies. Lack of access to relevant data, high implementation costs and the need to train employees can be limiting factors. The application of artificial intelligence (AI) and robotic process automation (RPA) in accounting and finance is gaining importance in both academic research and business practice. These technologies not only affect the operational efficiency of accounting offices, but also redefine the professional roles of accountants and the organizational structure of accounting processes.

Januszewski, Kujawski and Buchalska-Sugajska (2021) analyzed the potential for and barriers to the application of process robotization in accounting service firms. Among other things, the authors highlighted the possibility of eliminating errors, reducing costs and increasing efficiency, but they also noted implementation difficulties, such as a lack of adequate competence or employee concerns. Łada and Martinek-Jaguszewska (2023) presented the phenomenon of accounting autonomization, pointing to changes in the nature of accountants' work and the shift from operational activities to analytical and advisory functions. This process is part of a broader transformation associated with digital transformation. Similar research was also conducted by Schulze (2023). Tiron-Tudor and Deliu (2021), on the other hand, emphasize the role of human-algorithm relationships in auditing, stressing the importance of being able to collaborate with AI systems and use them in risk assessment or anomaly analysis. In turn, Stafie et al. (2021) conducted a bibliometric analysis that demonstrates the growth of interest in AI topics in accounting in recent years, especially in the context of data analysis and auditing.

Fülöp and Măgdaş (2022) and Kokina et al. (2021) point to the need to redefine the competencies of accountants in the age of automation. The accounting profession now requires knowledge of IT, data analytics and systems thinking. Kokina calls for the development of an “accountant-innovator” attitude that actively co-creates digital solutions. Zhang et al. (2022) conducted a case study analysis of RPA implementations in various areas of accounting, such as financial reporting and tax accounting, showing both benefits (e.g., speed, data integrity) and challenges (e.g., oversight, data security).

In the Polish literature, this topic is taken up, among others, by Łada and Barszczak (2024), who introduce the concept of hybrid accounting - cooperation between a human and an accounting bot - and by Martinek-Jaguszewska and Łada (2024), who attempt to record the work of bots within the framework of so-called “virtual robot accounting.” An interesting proposal is the RPA feasibility assessment framework proposed by Wellmann et al. (2020), which allows an analysis of the viability of robotic deployments in specific business areas, including in accounting offices. In the context of public policy and taxation, Fornalik and Ziętek (2019) analyze the impact of tax process automation on the functioning of tax advice, while Łada and Mierzejewska (2021) showcase the development of digital interfaces in taxpayer-tax authority relations. These topics are also elaborated on in a report by KPMG (2023), which shows that the digitization of tax reporting not only improves efficiency, but also increases transparency and the detection of irregularities.

Consulting reports such as Deloitte Insights (2020) provide practical guidance for companies implementing AI - from auditing organizational readiness to building data strategies and integrating with current ERP systems. A report by EY (2023) highlights the role of AI in forecasting and predictive analytics that can support financial management. Mookerjee and Rao (2021) identify RPA as a so-called disruptive technology - a disruptive technology that changes the logic of how the entire industry operates. While Zhang et al. (2021) present specific scenarios for implementing bots to support auditing and controlling processes. From an educational perspective, Üçoğlu (2020) and Alghafiqi (2022) analyzes the impact of AI on accounting curricula, advocating the inclusion of subjects related to analytics and expert systems, and Chukwuani (2024) examines the attitudes of future accountants toward automation - enthusiasm on the one hand, and fear of losing their jobs on the other.

Polish literature is increasingly considering the risks and ethical dilemmas associated with AI in accounting. Skuza and Lizak (2023) address the problem of oversight of decisions made by algorithms in the public sector. Prędkiewicz and Biegun (2024) note that AI can both promote sustainability and generate new risks - especially in the absence of regulation and model control. In turn, Ziółkowska (2024) and Tomaszek (2022) point to the need to integrate AI with other financial technologies (e.g., blockchain, big data) to build a new information ecosystem in finance and accounting.

Despite the studies cited above, it can be concluded that to date there is not much research in the literature on the implementation of AI in finance. Especially when it comes to the context of the application of AI in the work of accountants, auditing, or finance departments. Especially if we contrast the number of such studies with studies in other areas. For example, we can mention here numerous studies in the medical field, the customer service sector, or the industrial sector. On the other hand, it is worth noting that the last few years have seen a steady increase in interest in the aforementioned area and the possibilities of using AI in this aspect. This applies to almost all regions of the world.

3. Survey methodology and description of the survey sample

In order to obtain empirical data on the current status of the use of artificial intelligence (AI) technologies in the field of accounting and finance, a survey was conducted. The survey was quantitative in nature and was conducted among representatives of two groups of organizations: accounting offices and finance departments of large companies operating in Poland.

The survey questionnaire was developed in electronic form and made available to respondents via an online form. Questions in the survey included the scope and forms of application of AI tools, the level of familiarity with them in organizations, implementation plans, identified implementation barriers, as well as perceived benefits and anticipated impact of AI on the future of the accounting profession.

A total of 1090 complete responses were collected and statistically analyzed. Among the respondents, representatives of accounting offices dominated (77.1%), the rest were employees of the financial departments of large companies (22.9%) - Figure 1. The respondents represented entities of different sizes - from micro-enterprises to large corporations - which allowed a diverse and representative analysis of the issue.

The purpose of the study was not only to recognize the degree of advancement in the implementation of AI in accounting practice, but also to identify attitudes and expectations towards these technologies. The results served to verify the research hypotheses set and provided the basis for practical conclusions and proposals for further research directions.

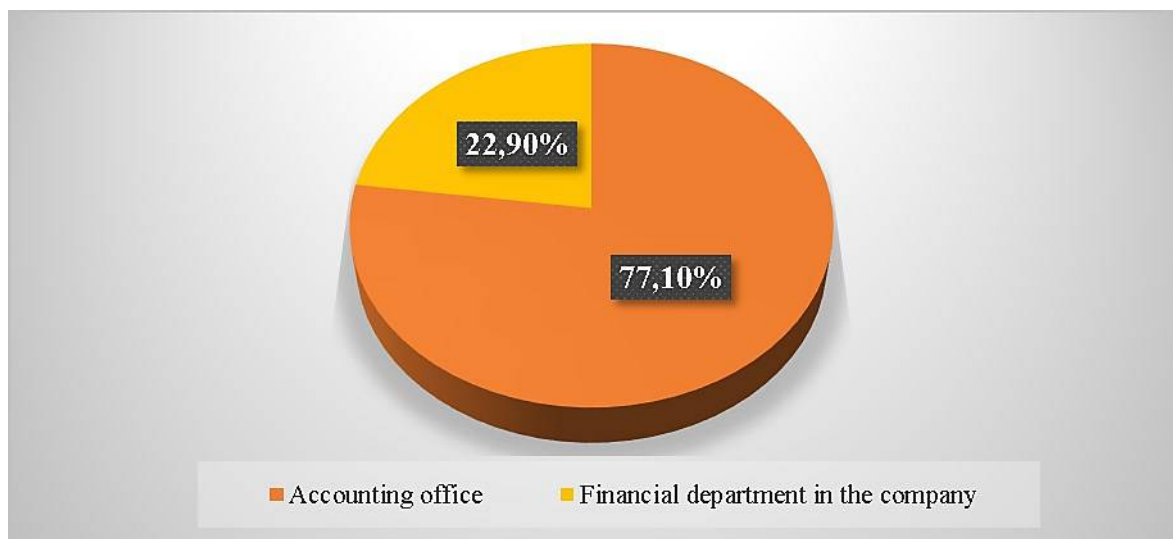


Figure 1. What type of organization do you work for?

Source: own study.

The vast majority of survey participants (77.1%) work in accounting offices, while 22.9% work in the finance departments of large companies. This indicates the survey's strong focus on the typical accounting services environment, but with the perspective of internal finance departments also taken into account. Figure 2 shows the survey sample by organization size.

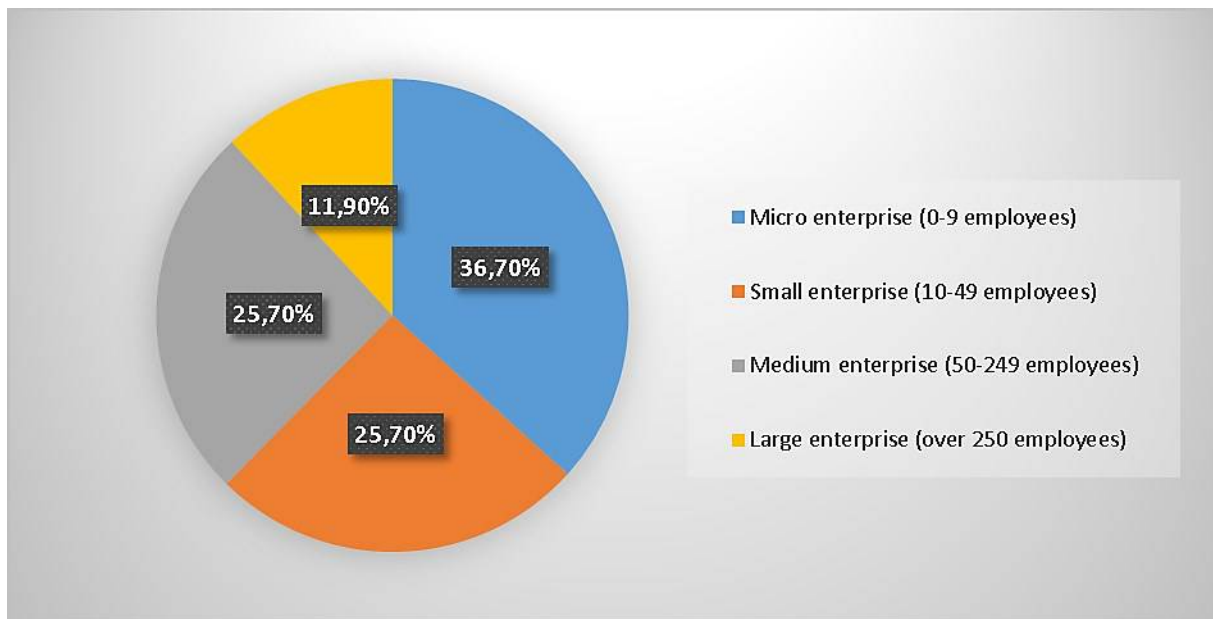


Figure 2. Size of the organization.

Source: own study.

Respondents were mainly from micro (36.7%), small (25.7%) and medium-sized enterprises (25.7%), and only 11.9% from large organizations. This shows that the accounting and financial services market is still strongly represented by smaller units.

Based on the survey questionnaire, three research hypotheses were formulated.

1. The most common barriers to implementing AI in accounting are financial constraints and lack of qualified personnel.
2. Most respondents see the future potential of AI in accounting, even if they do not use it.
3. Openness to implementing AI increases with prior experience in using digital technologies (e.g., RPA, ERP).

The adopted research design and formulated hypotheses provided a structured basis for assessing the current state of AI adoption in accounting and for identifying key factors influencing its future development.

4. Survey results

This section presents the most important results from the study. When asked whether the surveyed organization currently uses AI tools in accounting or finance, nearly half of them answered affirmatively. Almost half of the organizations (46.8%) already use AI tools, and another 45.9% plan to implement them. Only 7.3% do not intend to use AI, which proves the high openness of the sector to new technologies (Figure 3).

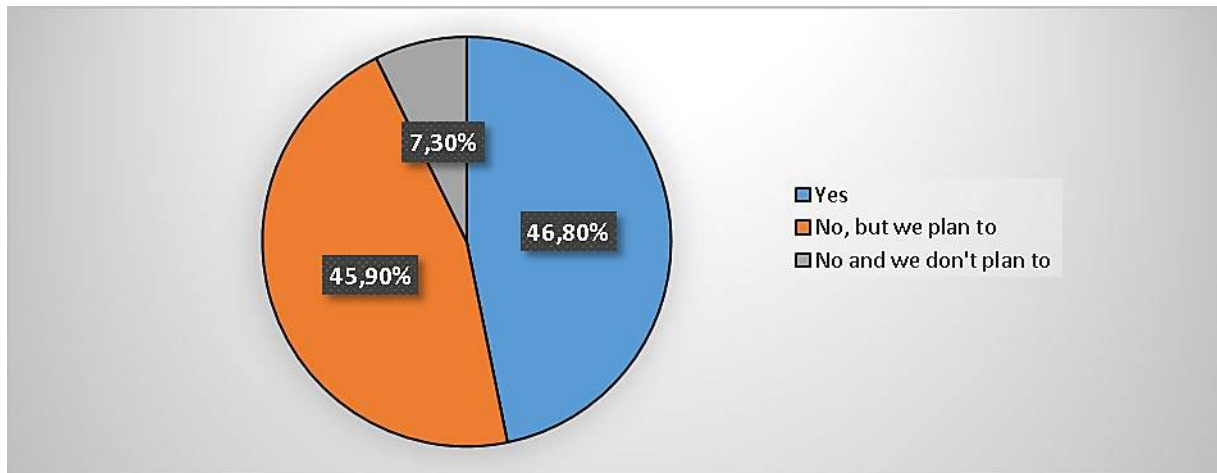


Figure 3. Does your organization currently use artificial intelligence tools in accounting or finance?

Source: own study.

When asked what are the main benefits of implementing AI, the most frequently mentioned benefits were:

- Time savings (67.3%).
- Reduction of operating costs (52.3%).
- Reduction of accounting errors (21.5%).

This indicates high expectations related to automation and improved work efficiency (figure 4).

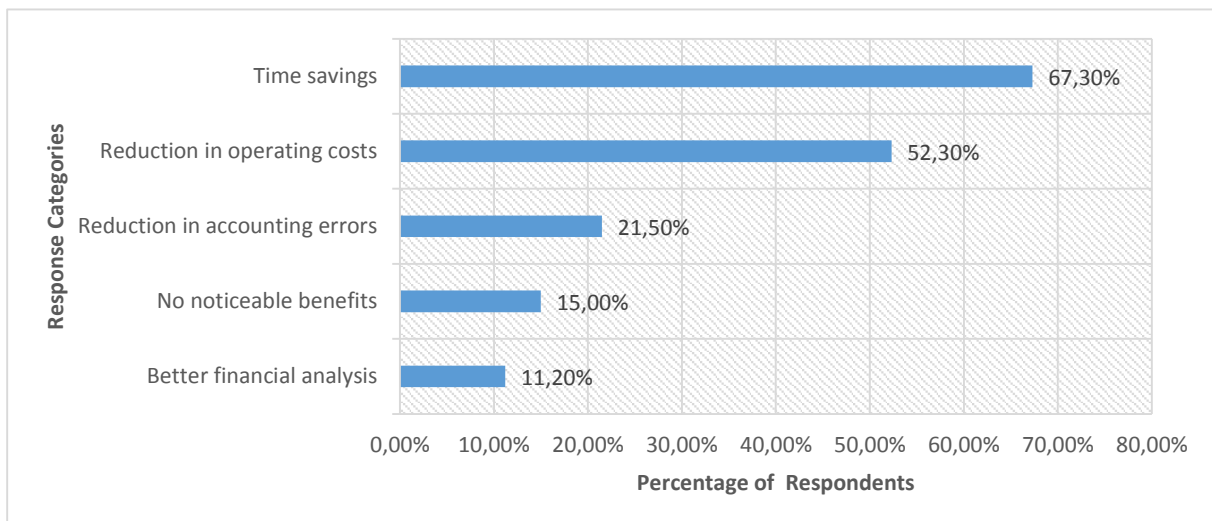


Figure 4. What are the main benefits of implementing AI – could you choose multiple answers?

Source: own study.

When asked how you assess the future of AI in accounting and finance, more than half of respondents (52.3%) believe that AI will support accountants, but will not replace them. At the same time, as many as 24.8% believe that AI will completely automate the work of accountants in the future (figure 5).

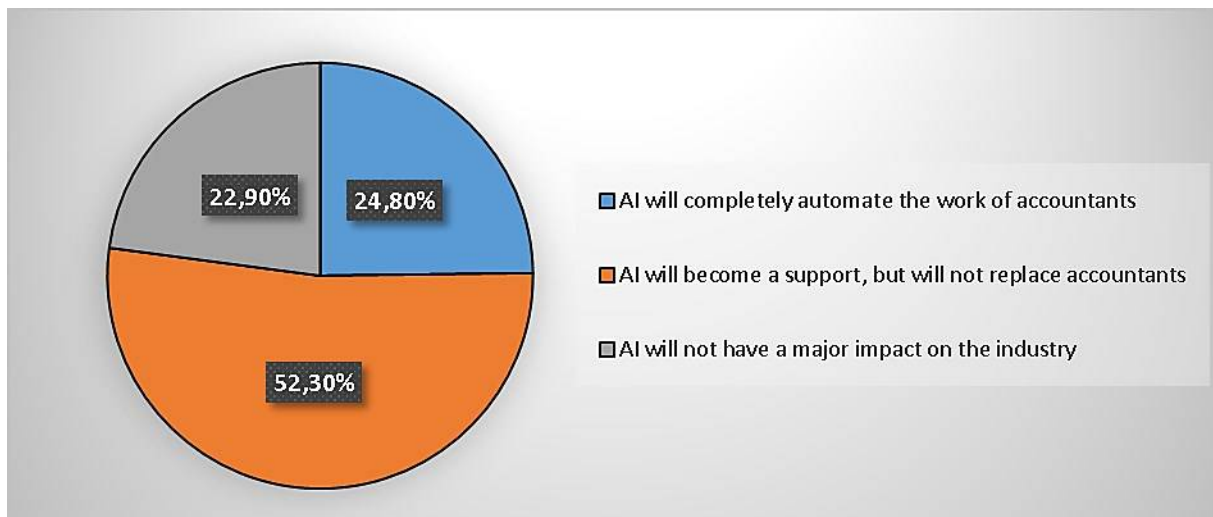


Figure 5. How do you assess the future of AI in accounting and finance?

Source: own study.

In turn, when asked whether your organization plans to implement AI in the next 3 years, the surveyed companies are strongly divided. 38.9% plan to implement AI within 3 years, 39.8% do not plan, and 21.3% have not made a decision yet. This indicates the need for further education and development of solutions tailored to different needs (figure 6).

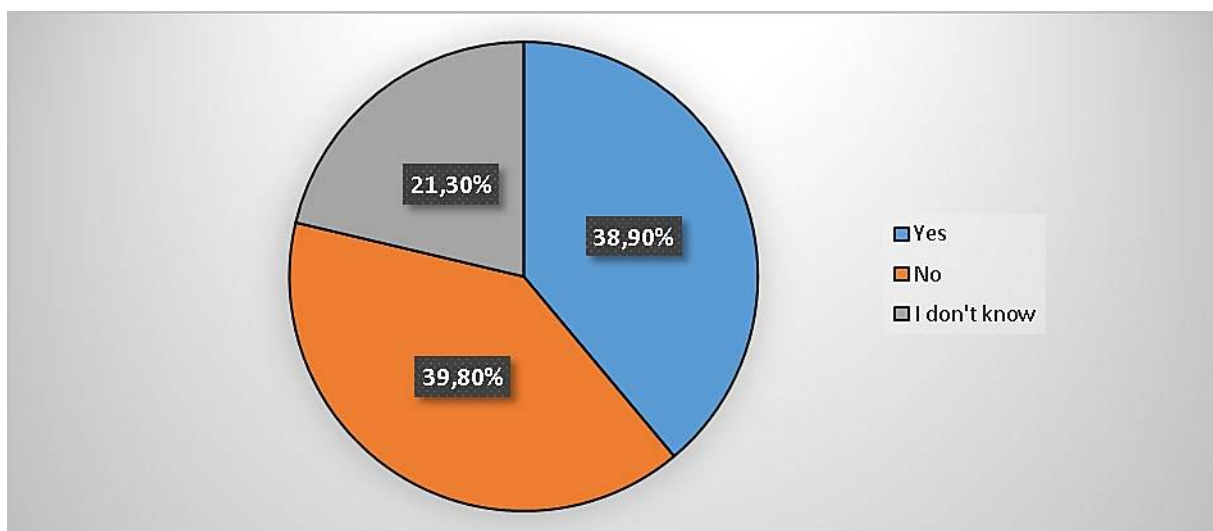


Figure 6. Is your organization planning to implement AI in the next 3 years?

Source: own study.

In turn, when asked to what extent AI could help the most in the work of an accountant/financier, it was indicated that AI has the greatest potential in:

- Optimization of operating costs (35.8%).
- Automation of repetitive processes (33.0%).
- Risk analysis and detection of irregularities (12.8%).

Customer service using AI is considered a lower priority (figure 7).

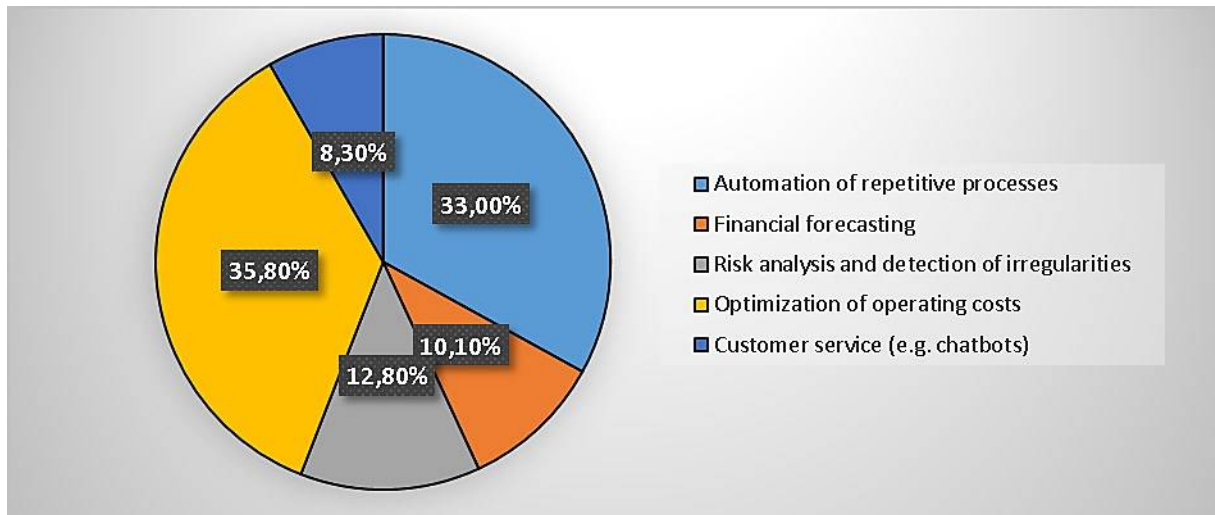


Figure 7. To what extent could AI most help in the work of an accountant/financier?

Source: own study.

When asked how quickly do you think AI will become widely used in accounting? More than half of the respondents (50.5%) believe that AI will become widely used in accounting within 2-5 years. Optimistic forecasts indicate a rapidly progressing transformation of the sector (figure 8).

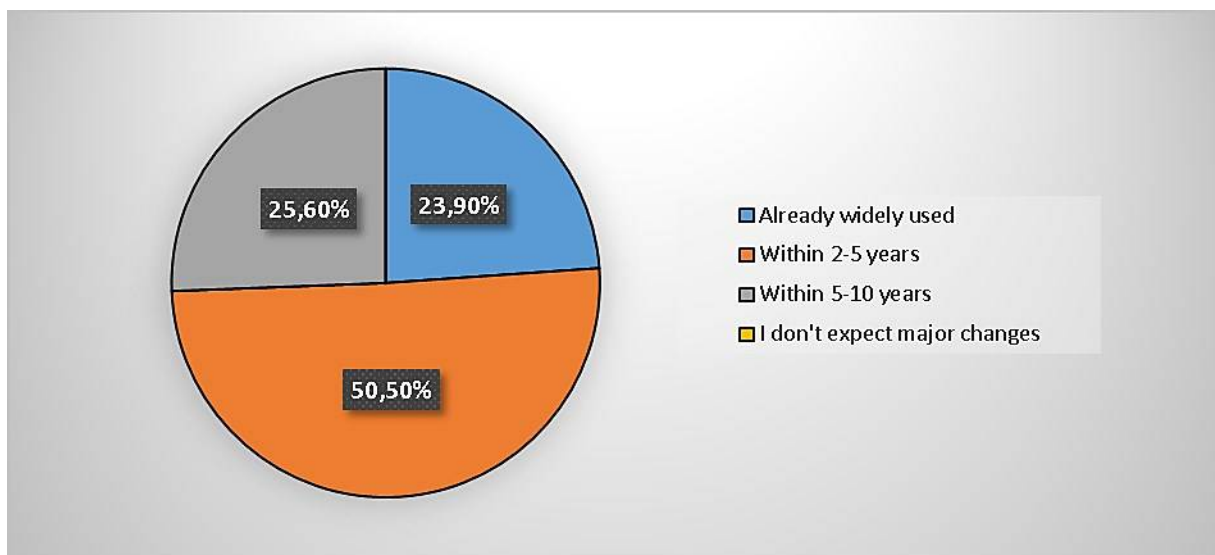


Figure 8. How quickly do you think AI will become widely used in accounting?

Source: own study.

The biggest barriers to AI implementation in the surveyed entities are:

- High implementation costs (72.5%).
- Concerns about data security (37.6%).
- Lack of knowledge about the technology (31.2%).

This indicates the need for education and adjustment of implementation costs for smaller entities (figure 9).

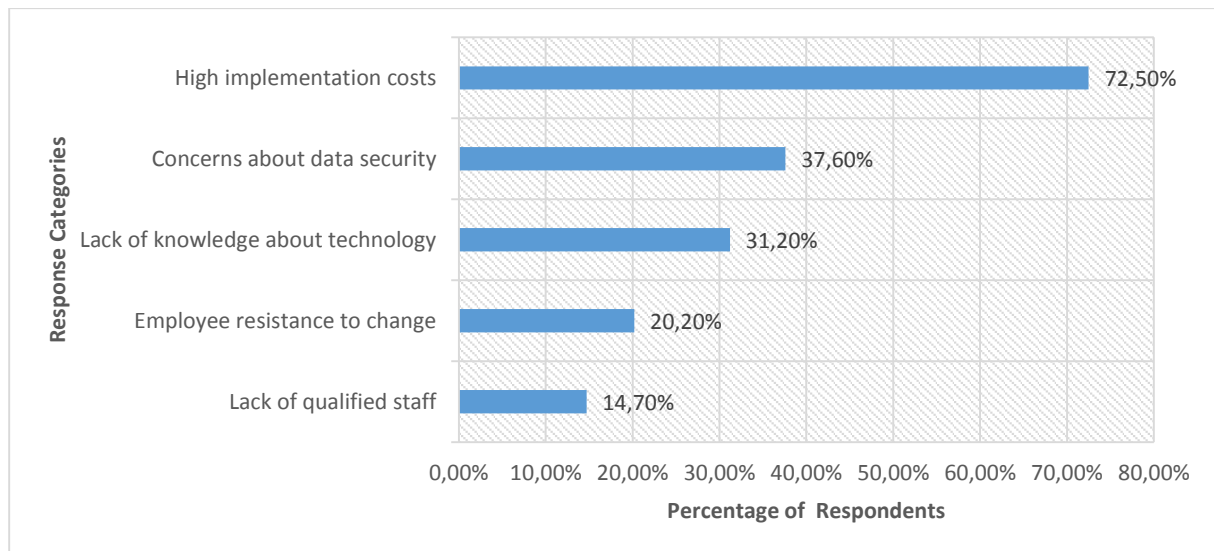


Figure 9. What are the biggest barriers to implementing AI in your organization (you can choose multiple answers).

Source: own study.

The question was also asked whether the surveyed company is already using AI tools in accounting or finance? Most organizations (54.1%) use free AI tools available online, and only 3.7% have dedicated AI solutions. This shows the low level of advanced AI integration in the accounting environment (figure 10).

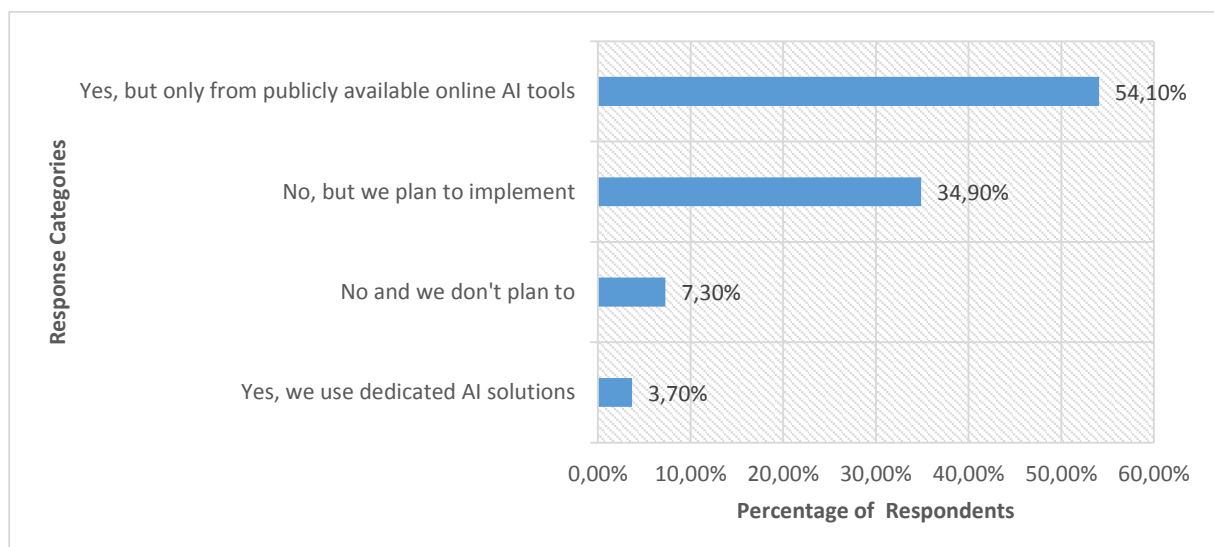


Figure 10. Does your organization currently use artificial intelligence tools in accounting or finance?

Source: own study.

The next question concerned the interest in implementing dedicated AI solutions in the future in the surveyed enterprises. Of the surveyed entities, only slightly over 10% of those surveyed do not see the need to implement AI-based tools in the future. Nearly two thirds of the surveyed declare that they may implement such solutions in their enterprises within 3-5 years (figure 11).

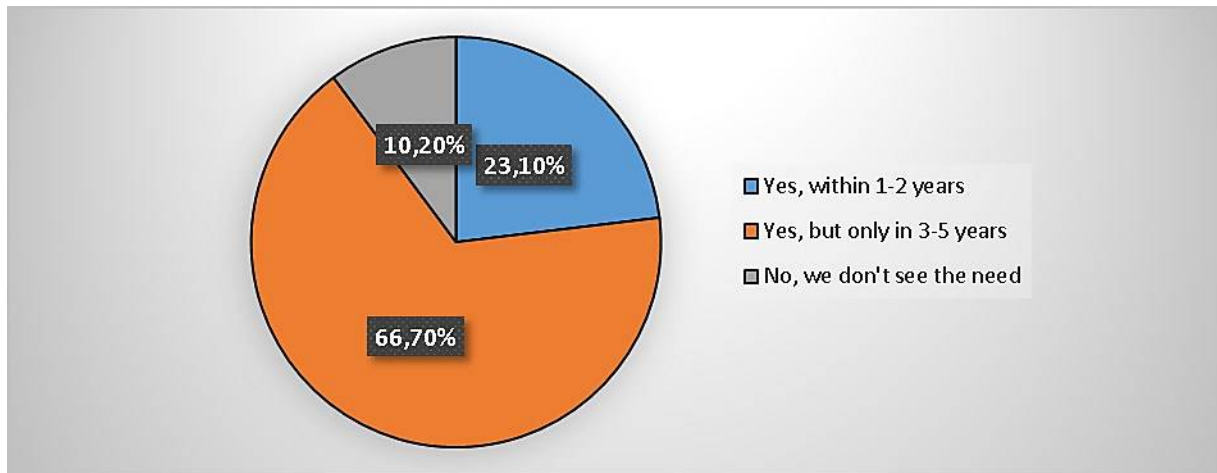


Figure 11. Would your organization be interested in implementing dedicated AI solutions in the future?

Source: own study.

When asked whether you think that using available online AI tools is sufficient or whether it would be better to implement dedicated AI systems in the organization, more than half of the respondents (51.4%) believe that dedicated AI systems would be a better solution than using only online tools (figure 12).

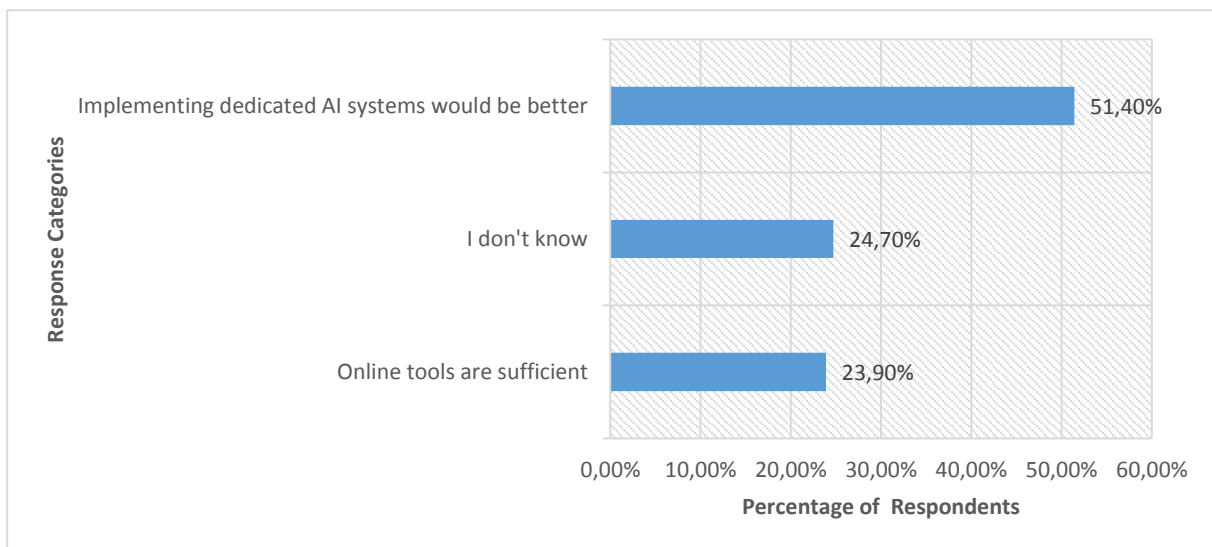


Figure 12. Do you think that using available online AI tools is sufficient or would it be better to implement dedicated AI systems in the organization?

Source: own study.

When asked what AI functionalities would be most useful in your work (you can choose multiple answers), respondents indicated primarily:

- Automation of accounting processes (63.3%).
- Detection of errors in documents (28.4%).
- Intelligent financial analysis and forecasting of results (25.7%).

Details regarding the indications are presented in Figure 13.

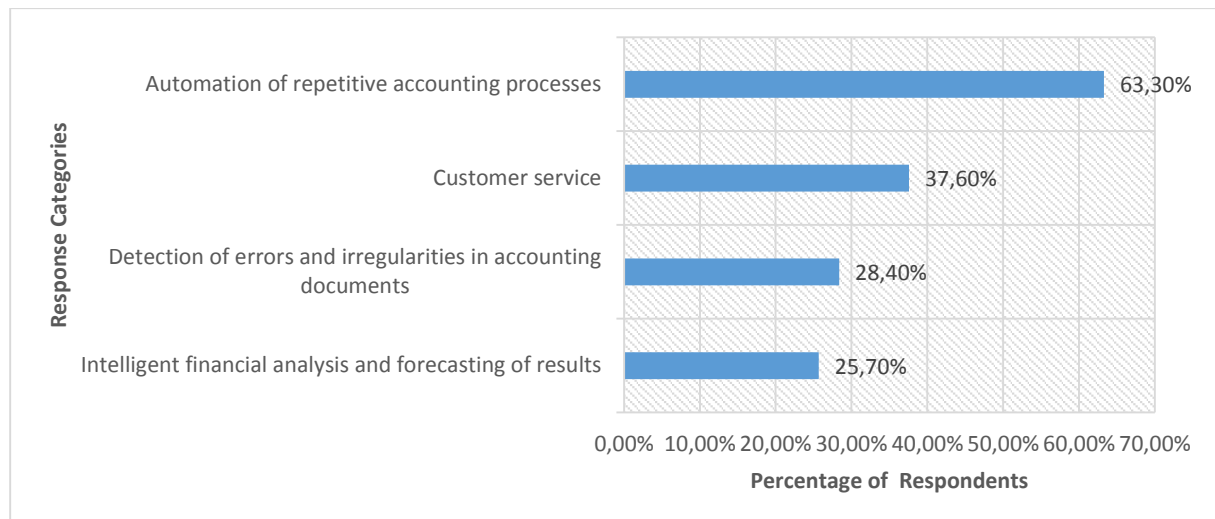


Figure 13. What AI functionalities would be most useful in your work (you can select multiple answers)?

Source: own study.

When it comes to the frequency of using online AI tools in accounting/financial work, most people use AI several times a week (32.1%) and several times a month (33.0%). This indicates the growing importance of AI tools in the daily work of accountants and financiers (figure 14).

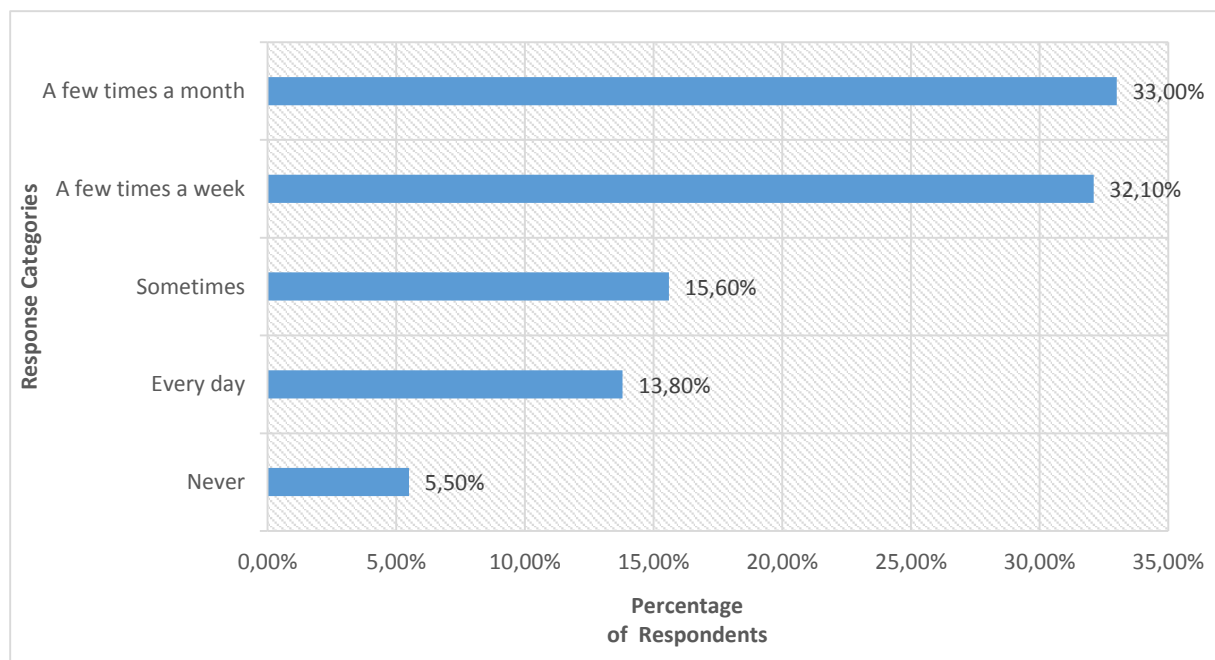


Figure 14. How often do you use online AI tools in your accounting/financial work?

Source: own study.

Among the surveyed companies that use AI, the most commonly used tools are:

- Chatbots for customer service (45.7%).
- Predictive analysis of finance (33.3%).
- Tools for automatic invoice recognition (23.8%).

Details regarding the indications are presented in Figure 15.

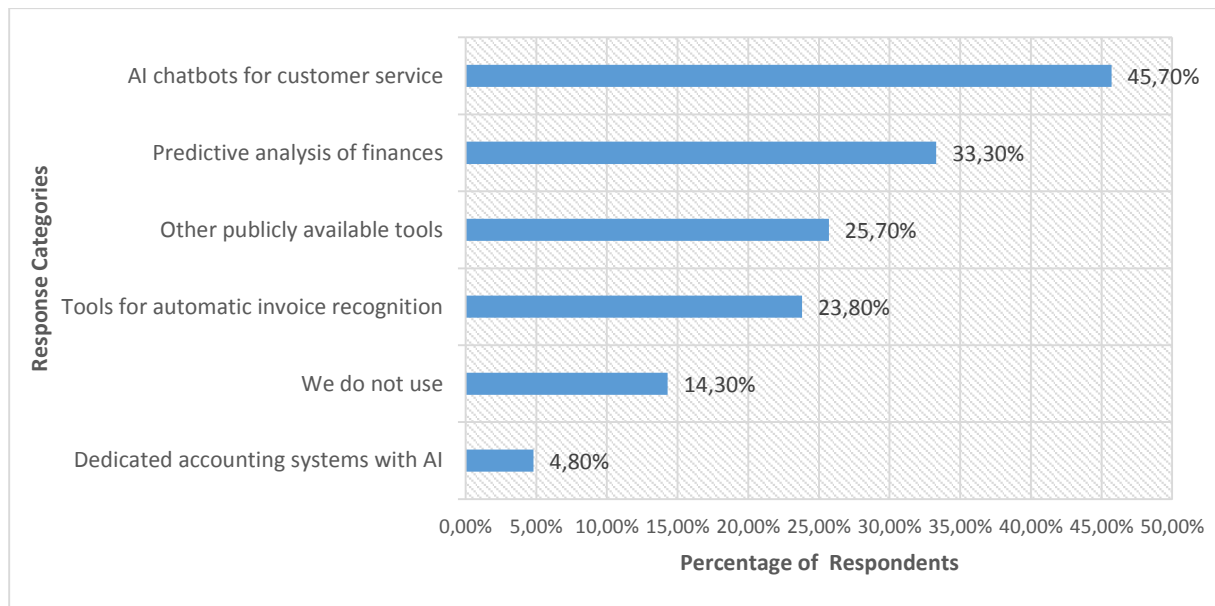


Figure 15. What AI tools do the surveyed companies use?

Source: own study.

The selected survey results presented above allowed for the verification of the research hypotheses. The first hypothesis stating that the most common barrier to implementing AI in accounting are financial constraints and lack of qualified personnel was partially confirmed. Indeed, the main barrier that was most often indicated, which is a significant limitation in implementing AI in accounting and finance work, is limited funds and high costs of advanced technologies. As for the lack of qualified personnel - in the opinion of the surveyed companies, this is not a key factor deciding whether AI will be included in accounting and finance work or not.

Hypothesis two, which states that most respondents see the future potential of AI in accounting, even if they do not use it, was verified positively. Indeed, even companies that do not currently use AI tools in their current work see the potential of such products.

Similarly, hypothesis 3, which stated that openness to AI implementation increases with previous experience in using digital technologies (e.g. RPA, ERP) was verified positively. The research results confirm the relationship between the use of AI tools and openness and willingness to reach for this type of technology. This indicates positive experiences related to the use of AI technology, which facilitates and speeds up the work of accountants and employees of financial departments.

In addition, it is worth pointing out the following key conclusions:

- High openness to AI: Most organizations are either already using AI or are planning to implement it in the near future.
- Critical importance of costs: The biggest barriers remain the costs of implementation and concerns about data security.
- Low level of technological advancement: The vast majority of organizations currently use basic online AI tools, not dedicated solutions.

- Growing expectations: Specific areas are indicated in which AI can bring the greatest benefits: automation, error analysis, intelligent forecasting.
- Need for education and support: Lack of knowledge about the technology and concerns about security indicate the need for training and the provision of simple, secure solutions.

Overall, the findings confirm that the adoption of AI in accounting is no longer a distant prospect but an emerging reality that requires strategic preparation and investment. The growing awareness of AI's potential, combined with the need to overcome cost and knowledge barriers, highlights the importance of proactive digital transformation in accounting and finance functions.

5. Summary and discussion

The conducted study identified key trends and barriers related to the implementation of artificial intelligence (AI) in accounting offices and financial departments of enterprises in Poland. The results clearly indicate that the financial and accounting sector is open to implementing AI-based technologies - almost half of the surveyed organizations are already using such solutions or are planning to implement them in the near future. The main expectations towards AI concern the automation of repetitive processes, reduction of operating costs and increase in efficiency. The phenomenon observed in the study is confirmed in the literature on the subject. For example, the studies by Fulop and Magdaş (2022) and Zhang et al. (2022) indicate that accounting and finance are among the areas most susceptible to automation thanks to AI. These conclusions are also consistent with the observations of Kokina and Gilleran (2021), who emphasized the growing importance of intelligent predictive tools in financial risk assessment.

At the same time, the study revealed existing challenges, the most important of which are the high costs of AI implementation, lack of sufficient technological knowledge and concerns about data security. These are barriers commonly indicated in global studies (e.g. Mookerjee, Rao, 2021), which suggests that the problem is global, not just local. It is also worth emphasizing that a large proportion of organizations still use only basic AI tools available online, which may limit their development potential. This indicates a growing need for the development of more affordable, yet technologically advanced dedicated solutions for the financial and accounting sector.

It is also worth pointing out some limitations of the conducted study. Here they are:

- Although the number of 1090 respondents is sufficient for basic analyses, broader conclusions for the entire population of enterprises in Poland should be formulated with caution.
- The predominance of small and medium-sized organizations may affect the nature of the results - the needs of large enterprises may be different.
- Self-assessment and declarations of respondents may be burdened with a subjective error, which is typical for survey studies.
- The study focuses on Poland and does not take into account the specificity of other markets, which limits the possibility of international comparisons.

Taking the above into account, it would be worth continuing the research. It would be worth conducting detailed comparative studies of AI implementation in various industries (e.g. industry, services, education) within the financial functions. It would also be possible to supplement the survey research with in-depth interviews with people responsible for AI implementation in organizations, which could provide more valuable, more detailed information. In further research, it is also worth focusing on measuring the actual impact of AI implementation on the efficiency, costs and quality of work in accounting and finance. In addition, studying AI implementations in various countries (e.g. Poland vs. Western European countries) would allow for a better understanding of the pace and nature of changes.

In a broader sense, the study highlights that the digital transformation of financial and accounting services is not only a technological but also a strategic and organizational challenge. The ability of companies to adapt AI effectively will likely become a key determinant of their competitiveness in the coming years. Therefore, future research should not only describe current trends but also develop practical models and best practices for successful AI adoption in the financial sector.

Moreover, the implementation of AI in accounting raises important ethical and legal considerations. Compliance with data protection regulations, including GDPR, is essential, requiring transparent handling of client information and proper safeguards for sensitive data. The concept of algorithmic accountability is becoming increasingly important, as organizations must be able to explain AI-driven decisions and provide mechanisms to correct potential errors. Ethical standards in the accounting profession remain crucial, as AI tools should support the integrity, transparency, and professionalism of financial reporting and advisory services. Integrating these aspects into research and practice reinforces the societal significance of AI adoption in accounting, highlighting the importance of responsible and legally compliant use of advanced technologies.

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EXPLORING THE POTENTIAL: A SWOT ANALYSIS OF BLOCKCHAIN ADOPTION IN THE AUDITING PROFESSION

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Purpose: The article aims to systematize the main benefits, drawbacks, opportunities, and risks of Blockchain Technology (BT) adoption in the auditing profession.

Design/methodology/approach: The research uses the SWOT analysis method, a critical literature review, and a bibliometric analysis of selected articles from the Scopus database.

Findings: Results show that researchers are aware of the pros and cons of BT adoption in audit, indicating real-time auditing, reducing the time and cost of audit, improving efficiency, ensuring transparency and immutability, but on the other side, a lack of regulations, changing auditors' role, requirement of training, implementation costs, risks regarding cybersecurity, and security of data. However, despite many challenges and threats, scientists argue that this technology will not replace auditors. Furthermore, BT can supplement auditors' analytical audit processes and enhance their professional judgment.

Practical implications: The significant value of this research enables practitioners to carefully consider and support decision-making regarding the implementation of BT in their audit companies.

Originality/value: Considering these conclusions, this article presents the current state of knowledge in this area. Also, it indicates a future research agenda for researchers and outlines implications for practitioners, teachers, and students. The bibliometric analysis and literature review identify a potential research area encompassing auditors' acceptance, the ethical aspects of BT use, and regulations.

Keywords: auditing, blockchain, adoption, SWOT analysis.

Category of the paper: Scientific research.

1. Introduction

In recent times, numerous innovations and technologies have emerged in the field of finance, including Artificial Intelligence (AI), Generative AI (such as ChatGPT), blockchain, and many others. In today's ever-evolving world, change is inevitable, including in the finance, accounting, and auditing professions.

The literature indicates that blockchain technology (BT), the Internet of Things, smart contracts, and artificial intelligence solutions serve distinct functions and can effectively address various financial reporting and auditing issues. Taken together, they have great potential to enhance the reliability of financial statement information and alter how companies typically operate (Roszkowska, 2021). Researchers and accounting professionals, in general, are trying to understand how BT can affect accounting and auditing, and what changes this technology can bring.

In the literature, the impact of BT on the future of auditing and potential risks (McGregor, 2020), its effect on audit risk (Dyball, 2021), and the challenges and resistance of auditors to BT (Pimentel et al., 2021) can be identified. The potential impact of BT was indicated by Brender et al. (2019). Firstly, the potential disruptive impact of technology on the audit profession has not been fully anticipated, and smaller audit firms are not prepared for the coming changes. Secondly, the auditing profession will undergo a paradigm shift in two ways: it will become more IT-oriented than accounting-oriented, and more forward-looking than backward-looking. Finally, the profile of auditors will change. The potential and implications of BT are also presented by Bonson and Bednarova (2019) in the context of challenges, i.e., scalability, flexibility, appropriate architecture, and cybersecurity.

The scientists also focus on current trends and future opportunities for use in accounting (Pimentel, Boulianne, 2020), as well as the benefits and challenges (Han et al., 2023), and new risks, changes in procedures, and additional opportunities (Bonyuet, 2020).

Nowadays, research is primarily focused on AI and BT issues from an accounting and auditing perspective, among others, using a wide range of research methods.

On the one hand, scientists have explored BT in accounting using the literature review method (Zemankova, 2019). Zhang et al. (2020) examined the impact of AI and BT on the accounting profession, identifying challenges and opportunities through a comprehensive review. Through a systematic literature review (SLR), Atik and Kelten (2021) identify the potential impact of BT on accounting and its possible effects. The literature review conducted by Han et al. (2023) highlights the benefits of BT and AI, as well as the challenges that await accountants and auditors. Garanina et al. (2022) provided a structured literature review of BT in accounting and identified main topics and trends. They claim that the four most commonly discussed areas of BT include the changing role of accountants, new challenges for auditors, the opportunities and challenges of BT application, and the regulation of cryptoassets.

Apart from SLR, Silva et al. (2022) conducted a bibliometric analysis to identify implications for the auditing environment, highlighting several new challenges related to the skills and knowledge required of audit professionals. Many studies employ bibliometric analysis, for example, to describe research trends and future directions in Big Data and AI within the accounting and auditing field (Agustí, Orta-Pérez, 2022; Pizzi et al., 2021).

On the other hand, Ziemba et al. (2025) noted that most researchers conduct empirical or conceptual studies using diverse approaches, methods, and tools. For instance, studies have used semi-structured interviews to explore the adoption of BT in accounting (Akter et al., 2024), including interviews with practitioners from both Big Four and non-Big Four firms (Parmoodeh, 2023). Other researchers have focused on statistical analysis (Huang et al., 2024) and conducted surveys exploring the influence of BT on accounting and auditing in various countries (Alkhwaldi et al., 2024; Elmaasrawy et al., 2024; Majeed, Taha, 2024; Qader, Kemal, 2024). Conceptual articles identified theoretical frameworks (Liu et al., 2022) or modeling understood as proposing a triple-entry accounting protocol (Pan, 2023).

As shown, opinions among researchers and practitioners are divided. In previous literature, scientists have employed various research methods. Furthermore, despite the growing number of empirical studies, Lombardi et al. (2022) emphasized the need for further empirical research and practitioner involvement, while also highlighting the importance of training requirements and education to bridge the gap between theory and practice. Bellucci et al. (2022), who conducted a systematic literature review (SLR) in accounting practice, highlighted an opportunity to perform future in-depth analyses to test new methods, including empirical and quantitative methods. Regarding the research area, Ziemba et al. (2025) highlighted issues related to impact, changes, challenges, opportunities, and auditors' perceptions of BT adoption as a future research direction. Additionally, Hakami et al. (2023) suggested that another area of future research could examine the potential benefits and challenges of using BT in these areas, as well as its implications for auditing standards and regulations. This article aims to address both identified research gaps.

In addition, the literature lacks a comprehensive, in-depth comparison of the primary features of BT adoption in the auditing area, using two research methods: a combination of SWOT and bibliometric analyses. Using SWOT analysis is valuable for both education (Keban, 2019) and management of technology (Nazarko, 2017). Therefore, it is necessary to compile the existing research and summarize the information in this area in order to point out to practitioners and researchers the wide range of features of BT and the possibilities of its application in auditing, so that they will have a better picture of the benefits and risks they have to face or will face and what challenges to expect. The overview should support auditors in the decision-making process and increase awareness of the opportunities and threats associated with adopting this technology in auditing companies. It also provides a comprehensive summary of BT's advantages and disadvantages in audits for academic societies, including students, teachers, and researchers. Therefore, academics, who are also educators, should focus on how best to train new and practicing auditors for this brave new world (Pimentel, Boulianne, 2020). Furthermore, it indicates potential research areas to examine in the future.

This article aims to systematize the benefits, drawbacks, opportunities, and risks of BT adoption in the auditing profession by categorizing them into four categories: strengths, weaknesses, opportunities, and threats (SWOT). To achieve the above objective, the following research questions were:

1. What are the strengths and weaknesses of BT in auditing that can be identified in the literature?
2. What opportunities and threats to BT in the auditing profession are identified in the literature?
3. What are the current trends and potential research directions of BT in the auditing area?

The remaining research is structured as follows. Section 2 presents the methodology. Section 3 provides the theoretical background, while Section 4 presents the findings and discussion. The conclusions and future research agenda are contained in Section 5.

2. Methodology

This study is based on a critical review of the current literature on BT adoption in the auditing field and a synthesis of the findings. The literature review identifies the main topics in the SWOT analysis framework: strengths, weaknesses, opportunities, and threats. The literature review included publications in English and articles published between 2017 and 2024 as of the end of September. Data for the bibliographic analysis were obtained from the Scopus database via a keyword search. An initial analysis of the search results for the keywords "blockchain" AND "audit*" in the Scopus database yielded 2,610 documents. Then, the search results were limited to financial fields directly related to the two subject areas: „Business, Management, and Accounting” and “Economics, Econometrics, and Finance”. Additionally, the search was limited to English. The final research search was conducted using the following query: TITLE-ABS-KEY (blockchain AND audit*) AND (LIMIT-TO (SUBJAREA , “ECON”) OR LIMIT-TO (SUBJAREA , “BUSI”)) AND LIMIT-TO (LANGUAGE , “English”)). The search results yielded 377 results. After that, the author provided a selection of articles on the relevance and importance of the analysis. The final number of selected articles is 34. The study selection process is detailed in Fig. 1. The PRISMA flow diagram identifies studies by searching with the refined research string and reporting the number of results obtained.

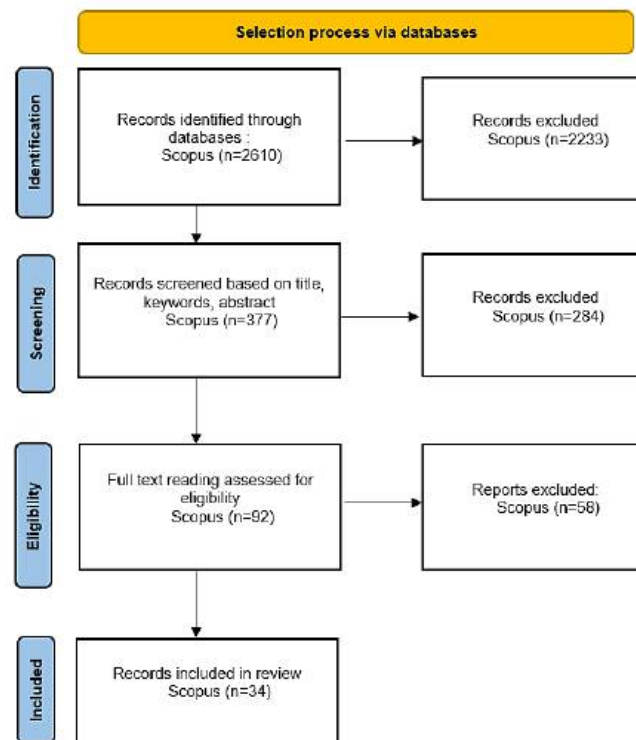


Figure 1. Diagram PRISMA.

Source: own elaboration.

This article also provides an in-depth examination of BT adoption in auditing across various methods and perspectives, helping readers understand its practical applications within the auditing profession. It narrows down to BT adoption exclusively from an auditing perspective, making it worthwhile for both interested parties - auditors and accountants. In the current literature, only a few articles using the SWOT analysis method have examined the influence of BT on the accounting profession, as provided by Lardo et al. (2022), Pramono (2020), and Tiron-Tudor et al. (2021). However, this research focuses solely on auditing and is based on the methodology employed by many authors (Farrokhnia, 2023; Tiron-Tudor et al., 2021; Pramono, 2020; Shevchuk, Radelytskyy, 2024).

A SWOT analysis enables the classification of the leading research areas related to the implementation and adoption of BT in the auditing profession. This classification includes four categories, namely strengths, weaknesses, opportunities, and threats, that can support a decision to implement BT in audit firms. The SWOT analysis is mainly based on selected articles from the Scopus database.

In addition to providing a more comprehensive summary of these four areas of BT adoption and identifying potential research areas, a bibliometric analysis was employed. Bibliometric analysis is based on the VOS viewer application for mapping science, which enriches literature analysis with a graphical presentation of keywords (Lardo, 2022; Mugwira, 2022). This method was also applied in systematic or critical literature reviews (Ziemba et al., 2025; Hakami et al., 2024).

A combination of critical literature analysis and planned qualitative research, using bibliometric analysis and SWOT analysis, can contribute to the development of science in the field of new technologies, notably BT in the auditing profession, to minimize undesirable effects in their professional practice.

3. Critical literature review

3.1. Strengths

Undeniably, BT can bring significant benefits and changes to the current auditing (Dai, Vasarhelyi, 2017). The major strength of BT implementation in auditing, indicated by many authors, is associated with improving efficiency (Elommal, Manita, 2022; Garanina et al., 2022; Han et al., 2023; Zemánková, 2019; Tan, Low, 2019), especially efficiency of recording, reconciling, and auditing of accounting data (Schmitz, Leoni, 2019). BT technology, by providing a distributed ledger (CPA, AICPA, 2017), ensures transparency and immutability of audit records. This strengthens the credibility of audit processes and enhances trust between auditors and their clients. Other benefits of BT include capacity, reliability, and data integrity (Han et al., 2023), as well as improved audit quality, operational efficiency, and the maximization of AI technology's capability to collect comprehensive information and data for rapid and accurate analysis (Zhang, 2020). Qader and Cek's (2024) research on BT and AI found a positive impact of their use on audit quality, aiding in the audit process and even facilitating fraud detection.

Many of these benefits are related to BT's real-time features. Changing the traditional approach to real-time auditing can ensure real-time inventory and transaction verification (Parmoodeh, 2023). As a result, BT streamlines time-consuming tasks, such as replacing current sampling practices (Han et al., 2023), the traditional method of gathering evidence, and confirming outstanding receivables and payables, by providing real-time verification (Zemánková, 2019). As a consequence, it results in lower auditing costs (Schmitz, Leoni, 2019; White et al., 2020) and frees up time for conducting more comprehensive and timely analyses.

Some results indicated a positive relationship between audit clients' use of BT and both inherent risk and control risk when auditing accounting estimates. The results also showed that BT enhances the collection of sufficient and appropriate audit evidence during the audit of accounting estimates (Elmaasrawy et al., 2024).

Additionally, BT employs advanced cryptographic techniques to protect data, making it highly immutable, tamper-proof, and resistant to manipulation or fraud (Parmoodeh, 2023). Audit firms can use this technology to securely store and transmit sensitive financial information, safeguarding it from unauthorized access. The transaction parties that execute

transactions accurately and securely depend on centralized processors that maintain their separate ledgers (CPA, AICPA, 2017).

3.2. Weaknesses

BT, like any other new technology, also has drawbacks and poses an obstacle to the auditors' profession. To gain a broader understanding of the BT implementation issue, which will be beneficial to practitioners in their decision-making, it is worth considering the other side of the coin. Challenges presented in the literature include investing in new technologies, addressing training needs for managers, employees, and auditors, and meeting the requirements of new regulations and accounting and auditing standards (Dai, Vasarhelyi, 2017).

Regulations serve as the primary procedural guidance for auditors and their firms. Currently, auditors lack regulatory certainty regarding new technologies. Given the novelty of this technology, there is a lack of regulations that cause barriers to BT adoption (Brender et al., 2019). The timing mismatch between the rapidly changing IT environment and the regulators' slow pace of releasing new or updated standards works against auditors. It is undeniable that more guidance is required to utilize BT as an audit tool (Gauthier, Brender, 2021), and auditors should familiarize themselves with the technology they will be using. Elommal and Manita (2022) emphasized the need for a clear, coherent legislative framework, along with new audit standards, to enable audit firms to implement BT and enhance auditing practices. However, it is unclear how audit standards should be updated or changed (Rozario, Thomas, 2019). Parmoodeh et al. (2023) also highlighted several challenges, including a lack of training and guidelines, as well as a need for improved understanding and awareness of procedures. In their research, one participant identified unfamiliarity with the technology as the most significant risk. Auditors primarily face a lack of knowledge and skills. This new challenge requires them to understand this technology and its implications in order to stay abreast of developments in the new BT ecosystem (Schmitz, Leoni, 2019; Silva et al., 2021; Tan, Low, 2019). Standards, guidelines, and training are needed to address the challenge BT will pose to the audit (Lombardi et al., 2022).

The subsequent weakness is related to the costs associated with implementing, integrating, and maintaining a BT (Fuller, Markelevich, 2020; Han et al., 2023; Liu, 2019). According to Cao et al. (2019), while the implementation of BT by auditors offers the benefit of cost savings through improved audit efficiency, it also entails indirect costs, such as the potential loss of clients who prefer traditional methods.

Some authors not only carefully highlight the potential benefits of BT but also identify challenges such as scalability, storage, flexibility, cybersecurity, and organizational complexity. Weaknesses in BT adoption are also apparent in the BT structure itself. First, BT cannot guarantee complete reliability and cannot store all data. Unfortunately, auditors must adjust their practices to BT, as there is no universal solution for each auditing firm's specific problems (Han et al., 2023). Other BT risks mentioned by Rozario and Thomas (2019)

include the potential theft or loss of digital wallets' private keys, errors in smart contract code, increased audit demands in a BT environment, higher computing power requirements, cybersecurity threats, litigation risks, and vulnerabilities in smart contracts.

Other studies (Akter et al., 2024) based on structured interviews highlight potential benefits, such as triple-entry accounting and real-time reporting, but also emphasize the challenges and lack of understanding regarding the use and advantages of BT in accounting, its complex integration with existing systems, and the higher costs linked to adopting it.

Most of the authors' considerations pertain to the application of BT in auditing, specifically from the perspective of implementing it within an audit firm. Dyball (2021, 2022) examines the application of BT during the audit of financial statements when used by an audited client. Results showed that clients using BT are seen as riskier than other customers (Dyball, 2021). In this case, both inherent and control risks are increased.

3.3. Opportunities

BT can also create numerous opportunities to enhance the auditors' profession in the future. It can be viewed as a reliable source of data for auditing, thereby enhancing the authenticity of audit data, providing a stable audit trail, and facilitating responses to audit data requests (Zhang et al., 2020).

Firstly, the excellent potential of BT lies in enhancing automated auditing processes, i.e., verification and automating audit activities continuously to test controls, analyze risks, identify exceptions or anomalies, analyze patterns, and review trends (Han et al., 2023). Through automation, auditors will no longer need to request many documents, which currently serve as the primary foundation for their controls. For this reason, the audit budget time could be reduced, and costs associated with fraud detection could be lowered (Parmoodeh, 2023). Likewise, BT can reduce costs by increasing audit efficiency, which can simultaneously increase transaction speed (Parmoodeh, 2023; Secinaro et al., 2021; Tan, Low, 2019) and enable more thorough scrutiny of clients' financial reports for data accuracy and regulatory compliance.

Automatization can not only save costs and time but also decrease or even eliminate human errors as well (Rozario, Vasarhelyi, 2018; Schmitz, Leoni, 2019; Zemánková, 2019) through the tests of controls (Šindelář, Dlask, 2021), automation of reconciliation of balancing items (Maffei et al., 2021), and transactions processes which reduce errors from maintaining a nonbiased record (Bonsón, Bednárová, 2019). Automation in the external confirmation process of accounting records facilitates inventory and data analysis (Maffei et al., 2021; Parmoodeh, 2023). Instead of verifying amounts or balances, auditors can reduce their efforts in testing financial information (Dai, Vasarhelyi, 2017) and focus on judgment, analytical procedures, complex transactions, testing controls, play a more strategic audit role, or develop new advisory services (Elommal, Manita, 2022; Parmoodeh, 2023). Thus, auditors can fully leverage BT's potential to simultaneously incorporate other analytical tools, thereby facilitating

analytical procedures (Parmoodeh, 2023). Moreover, Tan and Low (2019) expected that audit quality could be enhanced by reducing data recording errors and by strengthening fraud deterrence. Singhvi et al. (2021) highlight the potential of BT, expert systems, and machine learning to transform audit industry processes and emphasize the importance of new auditors understanding these emerging technologies.

Many of the opportunities associated with the adoption of BT are seen in the change of traditional auditing into continuous and comprehensive systems of control (Schmitz, Leoni, 2019), replacing manual and periodic reconciliation with automatic and real-time reconciliation, manual based on sampling with automatic confirmation of the entire population, manual sampling-based with an automatic inventory of the entire population, and manual sampling-based with an automatic data analysis of the entire population (Maffei et al., 2021). Current audit processes, such as recording transactions, processing data, storing information, and verifying the accuracy of recorded data (Maffei et al., 2021), will also transform. From the auditor's perspective, their role and profession will change due to BT (Schmitz, Leoni, 2019), and the scope of the decision will be different. Auditors will need to determine whether the corresponding contra-account has been correctly classified after payment is recorded (ICAEW, 2018) or verify that external parties providing online services for BT have ensured the reliability of these services in accordance with all applicable laws and regulations. They will mainly verify aspects that cannot be automated.

Some authors also indicate potential related to minimizing fraud risk (Liu et al., 2019; Tan, Low, 2019; Bonsón, Bednárová, 2019), enhancing fraud detection capabilities by providing a tamper-proof, immutable audit trail (Parmoodeh, 2023), or even preventing fraud by improving business information systems (Lombardi et al., 2022). This is because the reduction of the risk of attacks is ensured by distributing ledgers providing authenticity and reliability of audit data and various audit-related documents (Bonsón, Bednárová, 2019; Dai, Vasarhelyi, 2017; Zhang et al., 2020), as well as integrity and validation of data on BT platforms (Dyball, Seethamraju, 2021). Additionally, the timestamping of information in the BT reduces the cost of verifying false financial information (Zhang et al., 2020).

The last opportunity to evolve auditing practices concerns smart contracts, which are computer code stored on a blockchain. They allow counterparties to automate tasks manually through a third-party intermediary. Besides, smart contracts can accelerate business processes, reduce operational errors, and improve cost efficiency (CPA, AICPA, 2017; Rozario, Thomas, 2019; Schmitz, Leoni, 2019). According to Lombardi et al. (2022), smart contracts might also enable Audit 4.0 efficiency, reporting, disclosure, and transparency.

Therefore, it can be concluded that BT has excellent potential to supplement traditional auditing (Abdennadher et al., 2022). BT could offer a more comprehensive approach and alter the current audit paradigm. It would reduce audit costs, errors, and frauds, increase audit budget time, and, eventually, the efforts of auditors (Parmoodeh, 2023).

3.4. Threats

While BT can be perceived as a promising, emerging technology with great potential, it also poses threats to the auditors' profession, leading to significant changes. To understand the consequences and limitations of BT adoption, it is essential to examine the threats it poses, enabling users to manage them better and minimize as many risks and challenges as possible.

On the one hand, there are considerations that BT changes auditing, mainly through disruptions to the audit profession's status quo and the potential obsolescence of auditing standards (McGregor, Carpenter, 2020). Traditional audit practices are shifting toward IT audits, disrupting current audit practices by increasing the use of third-party confirmations rather than reducing the need for physical observation (Parmoodeh, 2023). Furthermore, small and medium-sized companies may be left behind by the large firms from The Big 4, which can take advantage of all audit firms in the market, resulting in an unequal gap between these two (Han et al., 2023).

On the other hand, some threats posed by the implementation of new technologies, including BT, are unmanageable and impossible to eliminate. They can be classified by type of risk. A few authors recognize security, operational, and other risks associated with, i.e., data confidentiality, private key management, business continuity and disaster recovery, information security, integration, scalability, regulatory, reputational, and IT compliance (Maffei et al., 2021), technological, data security, interoperability, and third-party vendor risks (White et al., 2020). For Šindelář (2021), the most significant risk from BT is the risk to integrity. Other risks are associated with permissionless blockchain (BT) platforms, arising from security vulnerabilities stemming from collaboration with numerous external parties (Dyball, Seethamraju, 2022). Dyball and Seethamraju (2021) identify the reasons for the impact on risk in their previous research. Firstly, it lacks technical, data, and governance standards. Secondly, there are negative implications for both inherent and control risks arising from uncertainty about the integrity of BT platforms. A lack of information about the impact of inherent risk can increase the uncertainty for the auditing clients BT uses. Thirdly, auditors appear to lack the ability to ensure the accuracy of information on BT platforms. Maffei et al. (2021) focus more on the risks and hazards of adopting BT in accounting and auditing practices, pointing out the following risks: underestimating possible manipulative and fraudulent practices, underestimating the risks of misclassifying and valuing accounts, lack of expertise when assessing business performance, and risks posed by inexperienced IT staff when adopting and operationalizing BT.

Furthermore, the adoption and implementation of BT can introduce new threats, including risks related to high energy consumption demand (Garanina et al., 2022), as well as the underestimation of potential risks or the incorrect use of BT tools (Maffei et al., 2021). Additionally, an accounting system based on BT, which provides financial data for auditing, may not yield sufficient and appropriate audit evidence (Maffei et al., 2021). Another challenge

for audit firms is the cost of BT implementation, which can create a barrier to BT adoption (McGregor, Carpenter, 2020).

BT poses a significant threat to the auditors' approach. On the one hand, trust in BT has led many practitioners and researchers to believe that auditors will become obsolete (Schmitz, Leoni, 2019). It may be related to auditors' expressed concerns about their technological competence in evaluating BTs (Pimentel, Boulianne, 2020). On the other hand, 45 percent of respondents believe that the lack of trust in this technology could delay BT adoption (PwC, 2018). The reason for the lack of trust in BT may be that auditors lack sufficient skills to utilize technology effectively, placing too much reliance on it rather than developing and practicing their professional judgment (McGregor, Carpenter, 2020).

Different auditors' approaches to BT technology lead to the next threat. The emergence of BT technology will require auditors to adapt their professional skepticism and critical thinking to new methods. BT adoption will require auditors to enhance their skills in qualitative and subjective areas, transitioning from quantitative processes to more qualitative, strategic, and process-oriented roles while still evaluating various aspects, such as classifications, recognitions, and management valuations (Parmoodeh, 2023). For instance, in case of the lack of a master copy of the database, auditors must be prepared for access responsibilities, timing, and speed of data availability, ensure completeness, integrity, and nonrepudiation of data, adequacy of validation controls and audit trail, and the existence of data backup and disaster recovery processes (Bonyuet, 2020). Therefore, Lombardi et al. (2022) suggest that there may be a potential need to reconsider or modify audit procedures accordingly, particularly in light of digitalization and BT adoption. Professional audit standards are not yet prepared to incorporate new trends into traditional audits (Zemánková, 2019).

Due to these threats, auditors are also exposed to technostress. It negatively affects auditors' perceptions of use, and the perceived usefulness of BT can be influenced by technostress (Shbail, 2023). Moreover, the success of BT adoption in auditing depends, among other factors, on auditors' perceived usefulness and ease of use (Alshurafat et al., 2022; Majeed, Taha, 2024; Shbail et al., 2023). Furthermore, according to Ferri et al. (2021), auditors' intentions and acceptance of the technology are also important issues. The results show that the main predictors of auditors' intention to use BT are performance expectations and social impact. Moreover, auditors' expected effort to implement and use the technology seems to be a reasonably reliable predictor. Auditors' knowledge about BT is positively associated with their use intention, indicating their optimism about this technology; their professional skepticism does not affect their intention. However, the perceived adequacy of accounting standards has an adverse effect, thereby weakening the effect of BT knowledge on intention, revealing a status quo bias in BT use (Juma'h, 2023). Acceptance is also related to technostress, which, according to Shbail et al. (2023), influences auditors' plans to adopt BT technology. The impact of technostress during technology use is also not overlooked in the research (Alshurafat et al., 2023). The results show that technostress affects the perceived usefulness and

ease of use of BT technology. The study found that perceived ease of use and perceived usefulness are significant predictors of attitudes toward the decision to use.

In connection with the above, auditors must consider the subsequent security implications. BT has limited ability to provide security and resistance to tampering and fraud, particularly in detecting fraudulent transactions (Schmitz, Leoni, 2019). After BT adoption, issues related to underestimation of fraudulent operations, hidden manipulation behind related-party transactions, classification errors, or evaluation issues were not a concern before BT implementation due to the use of ad hoc controls (Maffei et al., 2021). Although advantages include increased efficiency, lower costs, greater transparency, and a consistent audit history of all transactions, according to White et al. (2019), they are not without significant risks. These risks include technology, data security, interoperability, and third-party vendor risks. Due to the inherent advantages of BTs, auditors are required to provide assurance services to clients that use BTs and to offer guidance on BT technology. As such, auditors must be equipped with knowledge and experience in BT and assessing the risks associated with BT.

If auditors and their firms decide to implement BT, they will also face a dilemma about which type of BT to adopt for their company - private or public. There is a significant difference between these two blockchains. On the one hand, a public, or “permissionless” blockchain is accessible to any user on the Internet. Due to the lack of access controls, any unauthorized user can read or modify the data. On the other hand, BT, based on a private key, also known as “permissioned”, is shared only with certain participants, but it poses a danger that firms can modify or control transactions (Bonyuet, 2020). Given the 51% attack rule, data auditing can be compromised when a group of miners controls the absolute majority of power (Liu et al., 2019; Silva et al., 2021). It would influence the reliability of BT as a financial reporting tool, as any group with 51 percent of the computing power could modify the transaction history (Bonyuet, 2020). Han (2023) claimed that the risk of hacking is greater for private blockchains managed by administrators because hackers can infiltrate their networks or modify the content of the blockchains and the operating roles. For this reason, this decision has significant implications for safety and capacity.

4. Findings and Discussion

4.1. SWOT analysis

The biggest objection from professionals concerns the widespread claim that consensus verification can replace financial statements or the audits required for them. Understanding the audit community’s concerns can help guide future BT development and inform customized implementation (Sargent, 2022).

The above literature examples represent only a part of the issues planned for study and most often relate to BT and AI, or to audit and accounting issues. Due to differences arising from the definitions of these concepts, they should be considered separately. Therefore, this article provides a comprehensive, synthetic overview of the strengths, weaknesses, opportunities, and threats of BT adoption in auditing, thereby addressing the research gap in this area. Table 1 summarizes the considerations described in Section 3.

Table 1.
SWOT Analysis

Strengths	Weaknesses
• Improving the efficiency of recording, reconciling, and auditing accounting data. • Transparency and immutability of audited data. • Immutable, tamper-proof. • Resistant to manipulation or fraud. • Capacity, reliability, and data integrity. • Real-time audit, inventory, and verification. • Improving sufficient and appropriate collection during estimating. • Lower costs. • Time saving.	• Lack of regulations or standards. • Changes in audit role. • Required training and guidance for auditors. • Costs of implementation and maintenance of BT. • Scalability, storage, flexibility, cybersecurity, and organizational complexity. • Potential loss of clients. • Theft or loss of digital wallets' private keys. • Increasing clients' inherent and control risks.
Opportunities	Threats
• Improving the authenticity of audit data. • Enhancing automation auditing processes, i.e., verification, analysis of risks, and analysis of patterns. • Automatization in gathering data or documents. • Fraud detection and minimizing fraud risk. • Eliminating human errors (non-biased records). • Changing and supporting the traditional role of auditors. • Focusing on professional judgment and analytical procedures. • Developing new advisory services. • Manual based on sampling with automatic confirmation of the entire population. • Integrity and validation of data on blockchain platforms. • Smart contracts. • Audit 4.0.	• Obsolescence of auditing standards. • Shift to IT audit. • Ensuring the integrity. • Disruptions to the status quo of the audit profession and potential obsolescence of auditing standards. • Transitioning from quantitative processes to more qualitative. • Risks associated with, e.g., data confidentiality, private key management, business continuity, disaster recovery, information security, integration, scalability, etc. • Underestimating the risks of misclassifying and valuing accounts. • A high demand for energy consumption. • Adapting skepticism and critical thinking to new methods. • Technostress, lack of acceptance, and the impact of auditors' attitudes. • Necessity of database copy. • Risk of hacking for private blockchains.

Source: Own elaboration based on the critical literature review presented in Section 3.

Regarding the table above, the SWOT analysis results indicate that BT has strengths and opportunities in auditing, as well as weaknesses and threats. The SWOT analysis of BT adoption in the auditing profession reveals an area indicating potential alongside challenges that must be carefully navigated.

The adoption of BT in the auditing profession presents significant benefits and opportunities, namely automation and real-time audit, which lead to increased efficiency, transparency, immutability, and the integrity and reliability of data. It is immutable, tamper-

proof, and resistant to manipulation or fraud while also supporting numerous processes, resulting in reduced time and costs that revolutionize traditional practices and pave the way for a more trustworthy industry. The BT application offers several advantages, including enabling auditors to use a shared, synchronized ledger, thereby enhancing the credibility of audit processes. The robust security capabilities of BT avoid unauthorized access or manipulation of financial data. Its real-time auditing capability also allows auditors immediate access to data, making audits more efficient and providing a more comprehensive view of financial reports.

However, it is essential to note the weaknesses, challenges, and threats associated with blockchain adoption in auditing. The complexity of the technology requires auditors to invest in acquiring the necessary knowledge and skills. Furthermore, audit firms should pay more attention to various threats, including cybersecurity, scalability, and inherent and control risks. They must be aware of the current changes in auditors' roles and auditing processes, which are shifting towards more qualitative and IT audits. It is essential to be aware of the risks that may hinder the adoption of BT. The resistance to change within the auditing profession, as well as the inherent resistance to change in conventional practices, tends to inhibit the adoption of this transformative technology. In addition, scalability and performance limits, as well as interoperability among different BT platforms, require close attention to ensure there are no integration or compatibility issues. Audit firms should also consider gains and costs. They can achieve numerous benefits and high revenues as a result of cooperation with high-tech companies they audit. The use of modern technology and auditors' expertise in this field can elevate audit firms' service levels and result in more audit engagements. However, auditors' high knowledge and specialized skills can deter smaller companies from engaging them, due to the risk of high audit costs. Furthermore, audit firms also face higher costs, including the implementation of technology, appropriate IT systems, employee training, and the salaries of specialists they must hire.

Nevertheless, the opportunities presented by blockchain adoption in the auditing profession are significant. Blockchain's automated reconciliation and efficient data analysis can reduce errors and inconsistencies in financial reports, enhancing the reliability and accuracy of audits. Blockchain's transparency and auditability also enhance auditors' fraud-detection capabilities, providing a powerful tool for identifying and preventing fraudulent transactions.

For this reason, auditing firms should be aware of BT's features and recognize its revolutionary capabilities before implementing this technology. They must carefully navigate the weaknesses and threats associated with BT implementation to leverage its potential benefits fully. By focusing on strengths, overcoming weaknesses, seizing opportunities, and turning threats into strengths, auditors can leverage blockchain's implementation as a force for good, ushering in a new era of transparency, efficiency, and credibility in auditing.

4.2. Bibliometric analysis

Bibliometrics, a quantitative method for analyzing scientific literature, enables researchers to understand trends and patterns within their field. It is a helpful tool for researchers to assess the state of BT research in an audit (Hakami et al., 2023).

The bibliometric analysis used 34 articles selected from the Scopus database. After setting the frequency of occurrence to 3, VOSviewer proposed 90 keywords. Most of them were not related to the research area. Thus, 47 items were rejected. Finally, the VOS viewer map contains 43 items (keywords) related to BT and auditing. The selected keywords are divided into four clusters: Blue #1, Yellow #2, Red #3, and Green #4, as presented in Table 2.

Table 2.
Keywords in four clusters

No.	Colors	Authors' keywords	Occurrences	Total link strength
Cluster #1	blue	accounting	17	169
		benefit	5	49
		future	3	26
		need	6	68
		opportunity	7	85
		practice	10	101
		profession	11	121
		real-time	3	23
		role	5	56
		transaction	9	91
Cluster #2	yellow	challenge	9	101
		change	5	52
		client	4	42
		design methodology approach	11	139
		development	7	81
		impact	14	145
		originality value	11	139
		perception	4	52
		regulator	3	27
		risk	9	96
Cluster #3	red	analysis	7	79
		auditing	14	144
		audit quality	4	33
		audit procedure	7	67
		blockchain	32	305
		efficiency	6	59
		fraud	5	54
		implementation	5	67
		implication	13	147
		process	9	83
		reporting	6	53
		smart contracts	6	52
		transparency	7	76
Cluster #4	green	acceptance	4	43
		adoption	6	69
		auditor	19	184
		cost	7	85
		data	10	106
		effect	7	76
		evidence	9	105
		intention	5	49
		knowledge	6	69
		use	9	89

Source: Own elaboration based on the VOSviewer (van Eck, Waltman, 2010) and Renik et al. (2025).

To identify current trends in literature and future research gaps for scientists, the SWOT analysis was enhanced by utilizing the VOSviewer map and conducting a bibliometric analysis of the Scopus database. The data selected for the bibliometric analysis were obtained from Scopus articles based on the search described in section 2. As a result, selected articles for the SWOT analysis were included in the bibliometric analysis using the VOS viewer application. The results are presented in Figure 2 below.

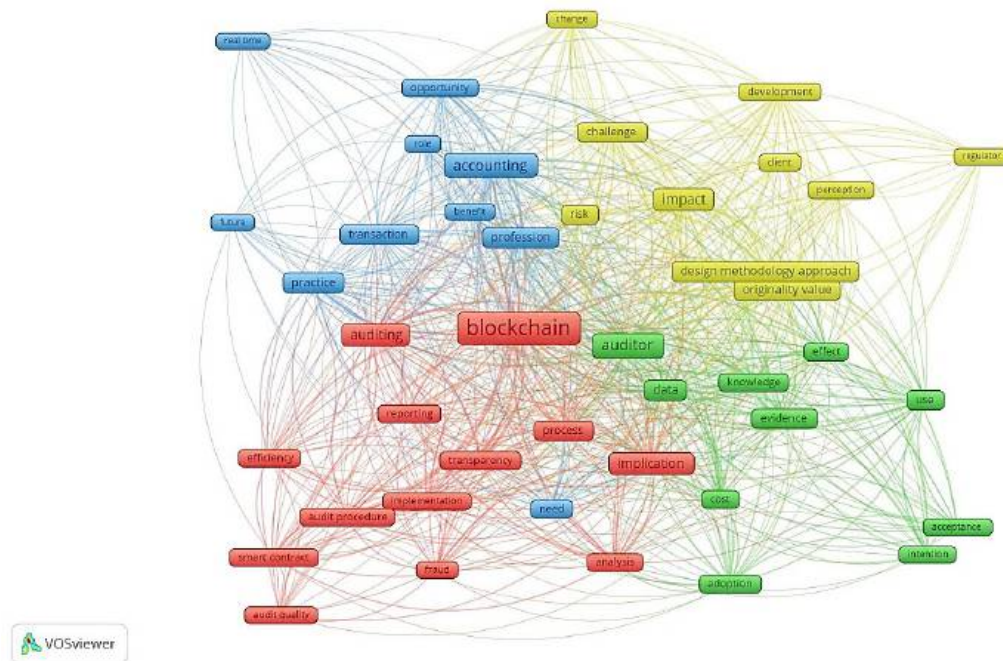


Figure 2. Bibliometric map from the VOS viewer application.

Source: own elaboration.

Based on the VOSviewer map analysis presented in Figure 2 and the keywords presented in Table 2, four main conclusions can be drawn.

Firstly, the blue cluster contains words related to the most positive aspects of SWOT analysis, namely strengths and opportunities in audit practice. It defines the future role of auditing practice and its benefits in the accounting and auditing profession. This cluster is based on 10 keywords contained in 21 articles used in the SWOT analysis. The furthest words from keywords in the middle of the map indicate a potential research gap. In this cluster, it is undeniably real-time.

The second (yellow) cluster represents the second part of the SWOT analysis: weaknesses and threats. It illustrates a connection between the impact of challenges and development, which can depend on risks and regulatory factors. It raises issues related to auditors' perception of changes and client perspectives. In this cluster, a future research direction is the changes and issues surrounding regulation. To analyze this cluster, 25 articles used in the SWOT analysis are reflected by 10 keywords.

The third (red) cluster focuses on practical issues related to procedures and processes, i.e., on the implementation stage. BT implementation in auditing can affect audit quality, transparency, and efficiency. The proposed solution for these features is seen in analysis, reporting, and smart contracts. In this case, the potential research gap may relate to audit quality. 13 keywords were used to analyze this cluster.

The fourth (green) cluster is more closely related to science, as it examines auditors' knowledge of BT's effects on adoption and use. The outermost keywords, least frequently explored in the research, are intention and acceptance, reflecting the research gap. This cluster is based on 10 keywords. In general, the keywords are most closely linked to the main keywords: blockchain, auditing, and auditor, which are related to practice, profession, design methodology, approach, knowledge, data, process, and reporting. They may reflect the most widely explored topics in current scientific research. On the other hand, the outermost keywords are real-time, change, regulator, acceptance, intention, and audit quality. They represent a potentially rare topic in the existing literature and offer potential future research directions.

As illustrated by the VOSviewer map, the bibliometric analysis highlights current trends in the BT area. Except for "blockchain", "auditor", and "auditing", the most common keywords in the VOSviewer map from each cluster are accounting, impact, implication, and data. It shows that areas have been thoroughly explored, aligning with the literature presented in the critical literature review and SWOT analysis sections.

Furthermore, this VOSviewer map helps scientists find future research directions by indicating gaps. Therefore, scientists should focus on different uninvestigated areas, such as future issues related to client perception, real-time auditing, regulators and regulations, audit quality, and auditors' acceptance. To fill this gap, these topics should impact efficiency and improve the knowledge required to make informed decisions about BT implementation for audit firms, as well as prepare auditors for changes.

4.3. Contribution to practice, science, and education

Sometimes the scientific and practical worlds differ, so, naturally, researchers and practitioners are not always in agreement about the potential of BT.

On the one hand, some scientists argue that the role of auditors and the traditional audit paradigm will change in the coming years or are already being changed by BT or other technologies (Abdennadher et al., 2022; Parmoodeh, 2023). Some practitioners believe they will not change, while others claim that they have already changed and will continue to change (Parmoodeh, 2023). Some authors even claim that auditors are becoming redundant or are forced to fundamentally alter their current roles and professional auditing standards, as these standards do not provide adequate guidance for auditors to use new technologies (McGregor, Carpenter, 2020). The ongoing digitization of the economy presents both challenges and opportunities for the auditing profession, requiring auditors and their clients to adapt (Tiberius,

Hirth, 2019). Moreover, the results show that the annual audit is increasingly evolving toward a continuous audit approach.

On the other hand, BT can be interpreted as both an opportunity and a threat or as benefits and limits (Abdennadher et al., 2022; Schmitz, Leoni, 2019). Some authors have a more positive attitude toward BT adoption, emphasizing opportunities rather than threats or limitations (Parmoodeh, 2023; Pizzi et al., 2021). Despite prevailing uncertainty, experts believe that new technologies will not replace auditors (Han et al., 2023; Maffei et al., 2021) but rather support them, and that auditors and their professional judgment will still be needed (Dai, Vasarhelyi, 2017; Garanina et al., 2022). It is speculated that the auditor role will be needed, for example, to verify judgments made in financial statements using blockchain-based Accounting Information Systems (Tan, Low, 2019), or they will be called upon ex-ante to verify transactions and even entire ecosystems using BT (Garanina et al., 2022). Additionally, there is a low probability of replacing professional skepticism auditors with an impersonal and mechanical control system based on BT in the future (CPA, AICPA, 2017; Schmitz, Leoni, 2019) if they can adjust their practices to this technology accordingly (Parmoodeh, 2023) and change or improve old methods and practices (Maffei et al., 2021).

BT auditing has been considered from two perspectives: enthusiasm about the potential and the risks associated with implementation (Lombardi et al., 2022). For this reason, auditors should not fear losing their jobs or being replaced by new technologies. They should be prepared for change and challenges, and perceive BT as an evolving tool that facilitates professional judgment and expedites auditing across many processes.

On the other hand, scientists present suggestions for professionals and educators, as well as the desired capabilities of job candidates (Zhang et al., 2020). The author believes that this study's implications are also helpful to researchers and individuals in education, including educators who teach students and students who may become future practitioners (accountants or auditors).

These groups should also be prepared for the changes that BT brings to science and education, because whether they will familiarize themselves with the benefits and drawbacks of BT implementation will depend on their pursuit of degrees or jobs and on potential future success in the profession. However, teachers should be open-minded to innovations and new technologies, not only to secure a promotion, but primarily to develop knowledge and practical skills to pass on to their students. They should serve as a guide and motivator for exploring technology in audit. Changes are unavoidable. For this reason, students and teachers should learn about BT, AI, and other new technologies as soon as possible.

This study can be used for educational purposes as a comprehensive guide to the benefits, drawbacks, opportunities, and risks of implementing and using BT in audit practice.

The article also outlines potential research directions and areas to be examined in the future. It provides examples of research questions and avenues for further research for both scientists and young researchers (students). Based on the literature review and bibliometric analysis, future research questions can be posed:

1. How has BT changed the auditor's profession and auditing procedures so far?
2. How do auditors respond to emerging technologies?
3. How will auditors' perceptions affect their decision about BT implementation and usage?
4. What are the possibilities for managing the disadvantages (challenges, weaknesses, and threats) associated with the use of BT in auditing?
5. What are the ethical dilemmas and moral aspects of BT implementation in the audit profession?
6. How did regulations change, and should they change in the future for the practical usage of BT in audit?

The presented areas should be investigated and studied using an empirical approach (Ziemba et al., 2025), drawing on empirical evidence, quantitative methods, and statistical tools to address research gaps from practitioners' perspectives.

Future research should focus on analyzing the benefits and challenges of using BT in audit firms, as well as the ethical issues auditors face. This analysis should also examine how auditors perceive the changes of the last few years and how they would improve the implementation and usage of BT in auditing.

These questions may provide valuable insights for scientists to further research, improve audit practices, streamline procedures, and change auditors' attitudes toward this innovation. This research is the first step in involving auditors in research, as understanding the limitations of BT adoption enables subsequent research to identify potential changes and improvements for more effective implementation. With that, auditors could change their perception and more willingly utilize this technology in their profession.

To summarize, continuous real-time auditing and automated observation may certainly facilitate auditors' work but also pose a risk, rendering the auditor's role irrelevant (Appelbaum, Nehmer, 2017). Auditing based on real-time BT effectively minimizes the need for physical observation and monitoring of business processes. Rather than traditional verification, auditors can observe which transaction timestamps were added and whether the blocks are hashed (Appelbaum, Nehmer, 2017).

In conclusion, the primary drawback of this technology is that it has not been thoroughly explored. With its implementation, there are many unknown factors, including inadequate regulations. Audit firms considering BT implementation also must consider whether they can afford the cost and effort of transformation. Additionally, auditors may experience uncertainty due to a lack of knowledge, skills, or clear guidelines. They will not be replaced by technology. Instead, BT will support their work so that they can focus on the more analytical tasks.

However, they should continually deepen and broaden their knowledge to complement their work.

5. Conclusion

BT, like most new technologies, can evoke a range of opinions depending on users' knowledge, experience, approach, or cultural background. Apart from the auditors' resources, BT has already changed its current audit tools (Zemánková, 2019).

Content analysis and bibliometric analysis of the literature allowed us to identify the main areas in terms of SWOT (strengths, weaknesses, opportunities, and threats). Regarding the SWOT analysis based on the literature, the main advantages of BT implementation include real-time audit and automated audit processes, which reduce time and costs and eliminate human errors. BT has excellent potential to innovate in auditing and enhance auditors' roles in control through automation, including data gathering, real-time record confirmation, risk analysis, and reconciliation. However, it could pose weaknesses and threats in data security, a lack of regulations, potential client loss, inherent and control risks, and the risk of hacking. It might pose challenges for auditors, including changes to the auditors' role, technostress, a lack of trust, and required training.

Scientists believe that it is rare for BT or other technology to replace auditors. It will be used in auditing. It would rather change its role and tasks during audits by using more IT tools, allowing it to focus on analytical tasks, make informed ethical decisions, and provide professional judgments. However, the authors' lack of unanimity encourages consideration of the actual advantages and disadvantages of BT adoption for auditing, as well as the opportunities and risks that might arise in the near future for the auditors' profession. Therefore, practitioners must be prepared and possess the necessary knowledge about the benefits and risks that the implementation and use of BT in auditing can entail.

Based on a bibliometric analysis, it can be concluded that current trends in the BT area have been thoroughly explored, encompassing accounting, impact, implication, and data, aligning with the literature presented in the critical literature review and SWOT analysis sections. Furthermore, the VOSviewer map showed that future research directions should focus on client perception, real-time auditing, regulators and regulations, audit quality, and auditors' acceptance.

This study can serve as a guide for researchers to develop this research area, as it categorizes the current state of the literature, highlights research gaps, and outlines potential future research directions. Additionally, it provides insights for students and teachers at universities to familiarize themselves with the benefits and current challenges of new technologies in auditing,

as well as for policymakers to provide appropriate guidance and adjust current laws to reflect the changing audit profession.

This article also provides valuable insights for auditors and management bodies, serving as a guide to decision-making on the pros and cons of BT adoption. Specifically, it explores whether audit firms should implement BT technology within their own companies or partner with clients to use BT. Audit firms consider BT implementation if they can afford the venture and expand their offer. For this reason, each audit firm must take an individual approach and adjust solutions to its specific profession.

This study is not devoid of limitations resulting from the author's subjective selection of articles for analysis. The analyzed publication was selected from the Scopus database, one of the largest databases, and other databases potentially containing different bibliographies were excluded. The literature provides numerous examples of research on new technologies, including blockchain, artificial intelligence, smart contracts, machine learning, and others, in the field of auditing and accounting. However, this study focused exclusively on blockchain technology in the auditing profession, excluding accounting from the investigation.

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EXPLORING RESILIENCE AND MARKET LOGICS IN AN EMERGING WINE REGION: EVIDENCE FROM POLAND (2014-2024)

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Purpose: This study offers the first comprehensive, current empirical portrait of Poland's wine sector (2014-2024) while proposing a theoretical framework that integrates personal resilience theory and meaning-making concepts with wine industry analysis. We aim to document the sector's structure and regional differentiation, and to establish foundations for future psychometric research on entrepreneurial persistence in marginal agricultural environments.

Design/methodology/approach: Data on producer numbers, vineyard areas, grape varieties, and wine production volumes across Poland's 16 voivodeships were obtained from the National Agricultural Support Centre (KOWR). Statistical analyses included descriptive statistics, Spearman's rank correlations, and hierarchical cluster analysis (Ward.D2 method). Findings were interpreted through the lens of personal resilience theory (Uchnast, 1997) and Frankl's concept of meaning-making.

Findings: Polish viticulture experienced remarkable growth between 2014 and 2024: vineyard area expanded six-fold (134 to 990 ha), wine production increased ten-fold, and approximately 250 grape varieties are now cultivated. Cluster analysis revealed three distinct regional groupings: leading wine regions (Lower Silesia, Lubuskie, Lesser Poland), intermediate regions with expanding southeastern frontier (*inter alia* Holy Cross, Subcarpathian, Lublin), and remaining regions facing climatic constraints. Western provinces favour larger-scale operations and are more eager to plant *V. vinifera* varieties (Riesling, Pinot Noir), while southeastern regions feature smaller family enterprises with greater PIWI hybrid adoption, suggesting divergent resilience-driven strategies.

Research limitations/implications: Data aggregation at voivodeship level constrains spatial precision. Future research should employ psychometric instruments to directly assess personal resilience among winemakers across regions, potentially with cross-national comparisons.

Practical implications: Policymakers should design regionally differentiated support instruments acknowledging the heterogeneous nature of Polish viticulture. PIWI varieties merit recognition in sustainable agriculture subsidy schemes.

Social implications: This study presents a comprehensive portrait of Polish winemaking – a sector currently experiencing notable public interest as part of broader trends in local food movements and wine tourism. Beyond documenting this emerging industry, the study highlights how non-economic motivations, including meaning-making and personal resilience,

drive entrepreneurial persistence in marginal agricultural sectors, offering valuable insights for rural development policy.

Originality/value: This is the first study to combine comprehensive national wine sector statistics with regional cluster analysis while applying personal resilience theory to explain entrepreneurial behaviour in an emerging European wine country. The study offers up-to-date empirical evidence based on the most recent registry data available (2014-2024), capturing a period of unprecedented sectoral growth. The dataset's richness, encompassing producer counts, vineyard areas, production volumes, and detailed varietal structure across all 16 Polish voivodeships, provides a uniquely granular foundation for understanding the dynamics of an emerging cool-climate wine region in Central Europe.

Keywords: wine economics, resilience, emerging markets, entrepreneurship, PIWI.

Category of the paper: Research paper.

1. Introduction

Over the past decade, Polish winemaking has experienced an impressive expansion (ten-fold increase in wine production and six-fold expansion in vineyard area), transforming from a niche activity into an increasingly recognized agricultural sector. This growth is particularly striking given Poland's location outside traditional wine latitudes and its marginal climatic conditions. In this paper, we propose a preliminary framework linking entrepreneurial resilience, particularly the capacity to accept risk and persist toward long-term goals despite adversity, to strategic decisions in emerging wine regions. Our analysis aims to establish a foundation for future psychometric research examining personal and organizational resilience in winemakers, with particular focus on emerging regions.

The fundamental objective of this paper is to provide the first comprehensive, current empirical assessment of Poland's wine sector based on complete 2014-2024 registry data. We interpret observed phenomena through market logic while also applying theories of entrepreneurial resilience and meaning-making processes. This theoretical lens is particularly appropriate for the wine sector in emerging wine countries, where producers often exhibit sustained commitment despite limited profitability, suggesting motivations beyond financial return. Understanding how the personality traits of winemakers – including, in particular, their personal resilience – relate to entrepreneurial behaviours is especially important in the context of marginal wine markets in Europe. In doing so, this study, in addition to providing empirical data on the Polish wine sector, proposes theoretical frameworks for subsequent psychometric research.

Wine is not merely another agricultural product. Viticulture carries a distinctive cultural load: symbolic, spiritual and identity-related weight that reaches far beyond the vineyard (Beltrán Peralta, Aulet, 2023; O'Boyle, 2021; Putzu, 2017). For many growers it may represent a long-term philosophical or existential commitment, reflecting more than climatic and economic constraints alone.

Poland lies outside the traditional European wine belt, and grape cultivation remains risky (Koźmiński, Mąkosza, Michalska, Nidzgorska-Lencewicz, 2020; Nidzgorska-Lencewicz, Mąkosza, Koźmiński, Michalska, 2024). Poland's viticultural heritage is marked by profound discontinuity. While wine production dates to the 10th century, it virtually vanished during the Little Ice Age (Kaplan, Suszyna, 2015). Interwar attempts to revive Polish viticulture were destroyed by WWII and post-war border changes: Poland lost its eastern viticultural territories to the USSR while gaining former German lands in the west, including 60 hectares of vineyards centred in Zielona Góra/Grünberg (Zarugiewicz, 1948). Communist authorities subsequently dismantled the industry in the 1960s (Bońkowski, 2022). Only with EU accession (2004) and regulatory liberalization, particularly the Wine Law of 2011 and Wine Products Act of 2021, did conditions emerge for genuine revival (Świdnicki, 2023). Poland's difficult viticultural history, combined with ongoing climatic challenges, suggests that the current expansion cannot be explained by profit motives alone and that the sector's repeated renewal may reflect the phenomenon of entrepreneurial resilience.

As mentioned above, despite climatic risks, especially linked to late spring frosts, which in 2024 alone destroyed up to 100% of yield in Western provinces (Głuszek, 2024) and regulatory framework still perceived as not yet fully friendly to small producers (Świdnicki, 2023), over the past decade, the area under vine and the number of winemakers in Poland have boomed. Financial profit seems an insufficient explanation for this surge of interest, particularly among entrants with no agricultural background. We therefore posit that non-economic factors, above all entrepreneurial resilience and a strong sense of meaning or mission, may influence the decision to establish a vineyard.

Previous studies have examined Polish wine primarily from an agribusiness perspective and relied on older data collected before the sector's recent six-fold expansion. To date, no publication has combined nationwide statistics with granular regional analysis while also applying an entrepreneurial resilience lens to winemakers' motivations and strategic persistence. Moreover, the current varietal structure of Polish vineyards, crucial for both productivity and regional identity, has not been analysed systematically.

This study's originality rests on three principal foundations. First, it provides the first comprehensive empirical examination of Poland's wine sector from a production perspective, including detailed analysis of strategic cultivar selection patterns and systematic compilation of data spanning 2014-2024 at the voivodeship level. Second, it presents an unprecedented detailed mapping of Poland's varietal structure, documenting the spatial distribution and strategic logic behind the cultivation of approximately 250 grape varieties across 16 administrative regions. Third, and perhaps most significantly, the study moves beyond descriptive sectoral analysis by applying theoretical frameworks from strategic management and psychology, specifically personal resilience theory and meaning-making processes, to explain the remarkable expansion of Polish viticulture under climatically marginal conditions.

In this paper, we ask the following research questions:

- RQ1. What is the current structure and recent growth trajectory of the Polish wine sector as of 2024?
- RQ2. Does Polish viticulture show distinct regional patterns in varietal structure, productivity and farm size?
- RQ3. How might personal resilience and meaning-making frameworks help explain strategic decision-making in emerging wine regions?

Adopting a dual perspective, we provide an empirical overview of the sector while proposing theoretical interpretations that link its appeal to personal resilience, the capacity to accept risk, abandon routine, remain open to novelty, and persist toward long-term goals (Uchnast, 1997). Poland's nascent wine industry thus becomes a natural laboratory for examining how meaning-making and resilience might influence entrepreneurial strategy in non-traditional viticultural settings. This exploratory investigation establishes foundations for future psychometric research testing these theoretical propositions.

2. Personal Resilience and Meaning-Making in Entrepreneurs

Entrepreneurial success in marginal environments requires more than economic calculation. Resilience, the dynamic process of recovering from adversity and persisting despite unfavourable conditions, may prove crucial for understanding vineyard establishment in climatically challenging regions where traditional profit maximization models fail to explain observed behaviour (Garmezy, 1991; Masten, Reed, 2002). Following Uchnast (1997), we conceptualize personal resilience as the capacity to accept risk, abandon routine, and persist toward long-term goals despite adversity. Uchnast's framework, integrating Maslow's (1943) security-versus-growth dilemma with Block's (1965) ego-resiliency, defines personal resilience as a continually developing capacity to cope, adapt, and engage under stressful conditions while preserving one's identity and life orientation. Individuals with high personal resilience accept risk, remain open to novelty, and persist toward long-term goals, whereas those with low resilience prioritize self-protection. This framework is particularly relevant for understanding vineyard establishment in climatically marginal regions.

Psychological (personal) resilience may explain entrepreneurial drive in circumstances where the classic assumption, i.e. the pursuit of profit, does not suffice (Dewi, 2024; Hayter, 2011) by emphasizing dispositional persistence and meaning-making over opportunity recognition or economic necessity. The resilience lens explains why entrepreneurs persist despite repeated setbacks in objectively unfavourable conditions, a pattern important in Poland's climatic and legal circumstances. This psychological dimension does not replace economic explanations but complements them where market incentives alone fail to predict

entrepreneurial persistence. The presence and growth of viticulture in difficult parts of the world, may be additionally illuminated by the Frankl's concept of meaning-making (Frankl, 1967, 2006). According to him, people derive meaning through creative values (what they contribute), experiential values (what they receive), and attitudinal values (how they respond to unchangeable circumstances).

Winemaking manifests both creative and attitudinal values: the winemaker and/or the winegrower creates and shares their product with the world while demonstrating resilience in the face of hardship. We propose that these psychological factors, integrated with market logic, provide a more complete explanation of strategic decisions in emerging wine regions and offer a management framework for understanding entrepreneurial persistence in marginal agricultural sectors.

3. Methods

The empirical data for this study were obtained through official correspondence with Poland's National Support Centre for Agriculture (Krajowy Ośrodek Wsparcia Rolnictwa, KOWR) in response to a public information request submitted under Poland's Access to Public Information Act (Reference: CEN.BDG.WB1.0144.208.2024.KRU.22). The comprehensive dataset includes producer numbers, vineyard areas, grape variety distributions, and wine production volumes across all Polish voivodeships (the 16 administrative provinces of Poland) for the period 2014-2024 (KOWR, 2024). Data on the average agricultural land area in individual voivodeships were obtained from the Agency for Restructuring and Modernisation of Agriculture (2024).

Statistical analyses included descriptive statistics, correlation analyses (Spearman's ρ). Spearman's rank correlation coefficient (ρ) was used due to the small sample size ($n = 16$ voivodeships) and the non-normal distribution of several variables. Statistical significance was set at $p < 0.05$. Hierarchical cluster analysis (Ward.D2 method, Euclidean distance, standardised) was additionally employed to identify regional groupings based on structural variables. Calculations and clustering analysis were performed using jamovi 2.3.

4. Results

4.1. Polish Wine Production Development (2014-2024)

Despite Poland's location north of the 49th parallel, climate change is making viticulture increasingly viable, particularly in western and southeastern provinces (Koźmiński et al., 2020; Maciejczak, Mikiciuk, 2018; Maciejewska, Olewnicki, Stangierska-Mazurkiewicz, Tyminski, Latocha, 2024; Świdnicki, 2023).

Poland's vineyard area for wine production reached 951 hectares in mid-2024 (ca. 990 ha in late 2024), representing a 608% increase from 134 hectares in 2015. The number of grape growers increased by 724% over the same period (see Figure 1).

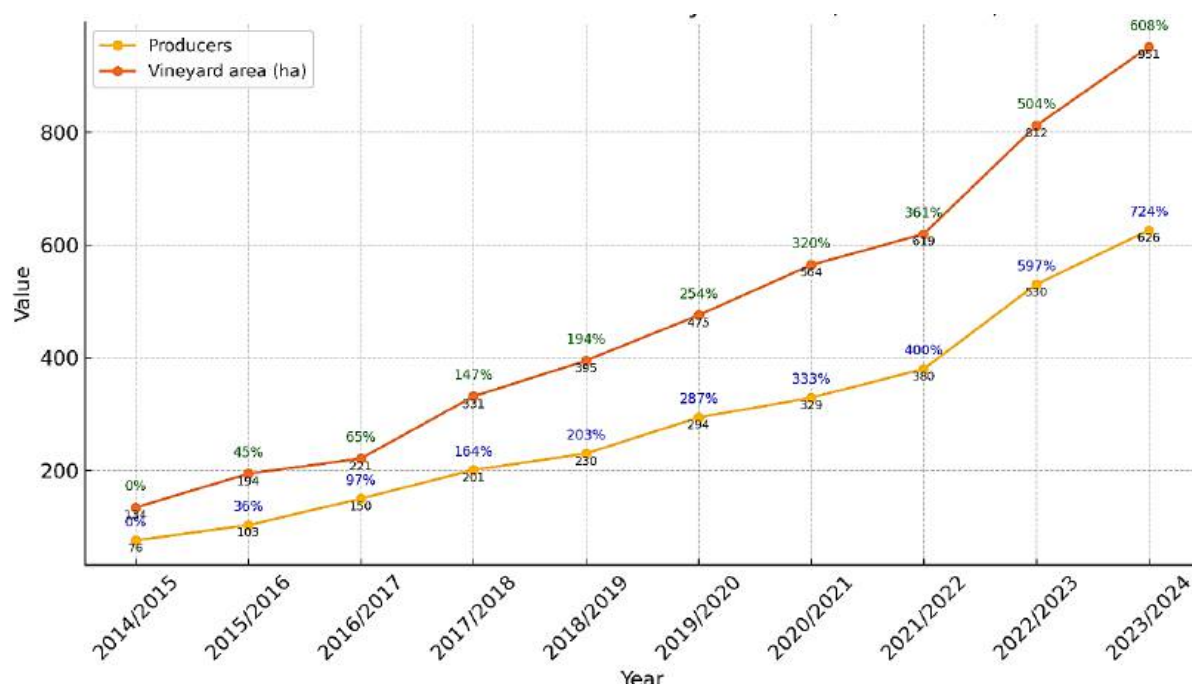


Figure 1. Growth of Producers and Vineyard Area in Poland, 2014-2024.

Source: Authors' own elaboration based on data from the National Support Centre for Agriculture (KOWR), letter ref. CEN.BDG.WBI.0144.208.2024.KRU.22, dated 11 December 2024.

Poland's wine production has increased nearly ten-fold over the past nine years, driven primarily by vineyard area expansion and, to a lesser extent, by productivity improvements (see Figure 2). In 2024, domestic producers yielded less than one glass of wine per adult citizen, approximately 97 millilitres, based on our calculations using Central Statistical Office data indicating 30.74 million adults in Poland. This pattern of sustained growth despite commercial uncertainty suggests high tolerance for ambiguity of environment, a key entrepreneurial resilience marker. Given that the average adult consumes around 6.8 litres¹ of wine and mead annually, domestic production remains far from meeting internal demand.

¹ Data from Krajowe Centrum Przeciwdziałania Uzależnieniom (National Centre for Addiction Prevention).

4.2. Geographical Clustering of Polish Wine Industry

Poland lacks a formally designated appellation system, so official vineyard statistics are compiled by voivodeships, which provide the spatial framework for our analysis. Figure 3 and Figure 4 demonstrate that cultivation is highly concentrated in a few provinces. Along the western border, particularly in Lubuskie and Lower Silesia, holdings are larger and yields higher, whereas in the southeastern provinces, Lesser Poland and Subcarpathian, producers work smaller plots. Climatically, these clusters correspond to Wine Regions I and II in the typology proposed by Maciejczak and Mikiciuk (2018).

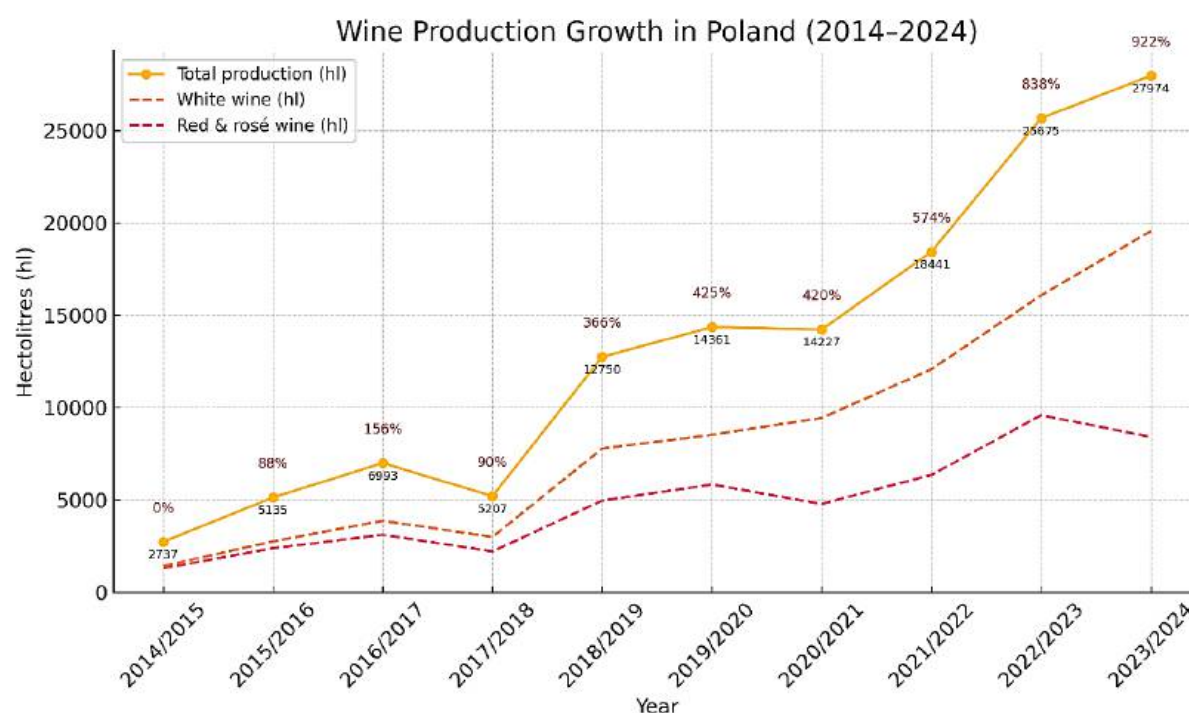


Figure 2. Wine Production Growth in Poland (2014-2024).

Source: Authors' own elaboration based on data from the National Support Centre for Agriculture (KOWR), letter ref. CEN.BDG.WBI.0144.208.2024.KRU.22, dated 11 December 2024.

The two macro-regions differ not only agronomically but also in a wide crime, etc.; differences rooted in their distinct historical legacies range of social and cultural indicators: voting behaviour, religiosity, divorce rates, differences rooted in their distinct historical legacies (Mordwa, 2012; Skorupska, 2023; Szukalski, 2016; Śleszyński et al., 2024). These structural contrasts may be mirrored in personal factors that shape winemaking decisions: perceived meaning and mission, motivation to start a winery, risk tolerance, varietal strategy, return expectations, and succession plans. Consistent with this pattern, southeastern producers typically run smaller, family-based operations with a less overtly commercial orientation, showing greater propensity to diversify plantings and experiment with non-mainstream cultivars.

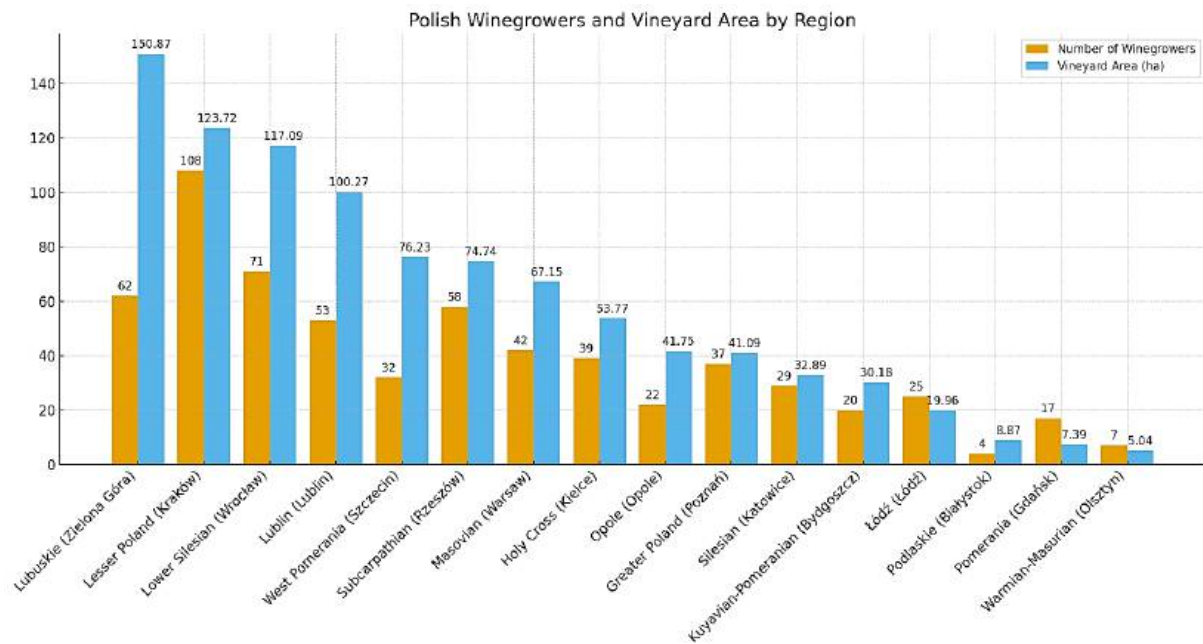


Figure 3. Number of Winegrowers and Vineyard Area by Voivodeship in Poland (2024).

Source: Authors' own elaboration based on data from the National Support Centre for Agriculture (KOWR), letter ref. CEN.BDG.WBI.0144.208.2024.KRU.22, dated 11 December 2024.

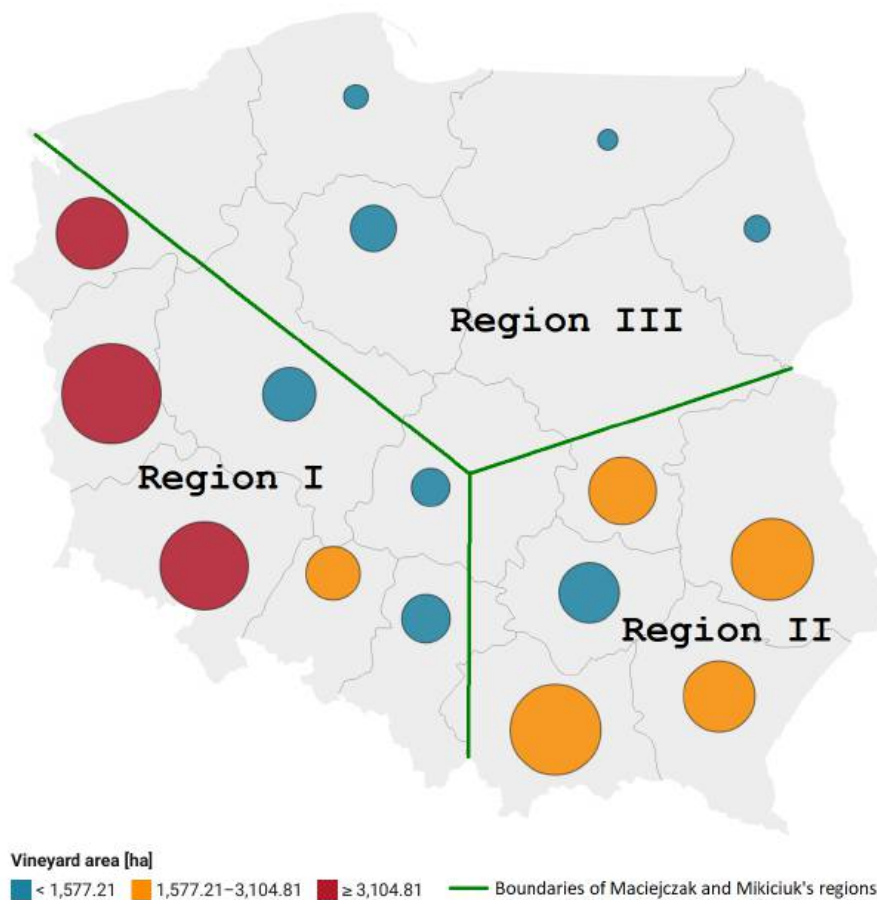


Figure 4. Vineyard Area by Province in Poland (2024) and Wine Regions.

Source: Authors' own elaboration using Datawrapper based on data from the National Support Centre for Agriculture (KOWR), letter ref. CEN.BDG.WBI.0144.208.2024.KRU.22, dated 11 December 2024.

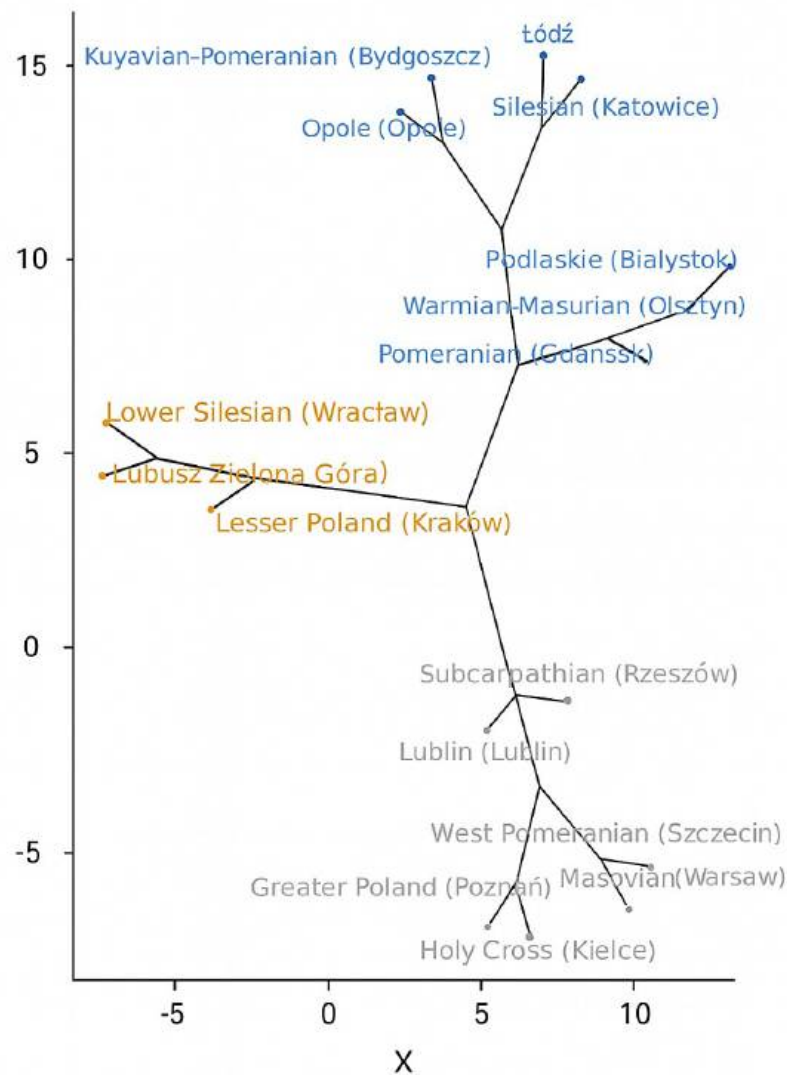


Figure 5. Cluster Dendrogram.

Source: Authors' own elaboration using jamovi based on data from the National Support Centre for Agriculture (KOWR), letter ref. CEN.BDG.WBI.0144.208.2024.KRU.22, dated 11 December 2024.

To empirically validate the regional differentiation observed in descriptive statistics, hierarchical cluster analysis was performed on Poland's 16 voivodeships using two structural variables: the number of registered grape growers and total vineyard area (hectares). Data were standardized prior to analysis; Euclidean distance and Ward's minimum variance method (Ward.D2) were applied. The resulting dendrogram (Figure 5) reveals three distinct clusters reflecting the sector's geographical concentration.

Cluster One (Leading wine regions) comprises Lower Silesia, Lubuskie, and Lesser Poland: the three voivodeships with the largest vineyard areas and highest producer counts. Notably, this cluster unites western (Lower Silesia, Lubuskie) and southern (Lesser Poland) provinces despite their divergent strategic profiles documented in Section 4.5, confirming that Poland's wine sector is dominated by two geographically distinct poles operating at comparable scale.

Cluster Two (Intermediate regions) includes Subcarpathian, Lublin, West Pomeranian, Masovian, Holy Cross, and Greater Poland. Within this cluster, Subcarpathian and Lublin provinces merge with the leading cluster at the lowest hierarchical distance, suggesting these southeastern regions represent an expanding frontier of Polish viticulture aligned with Wine Region II identified by Maciejczak and Mikiciuk (2018).

Cluster Three (Remaining regions) comprises Warmian-Masurian, Podlaskie, Pomeranian, Łódź, Kuyavian-Pomeranian, Silesian and Opole. Most regions in this cluster face genuine climatic constraints, aligning broadly with Wine Region III. Viticulture in these areas, while present, remains of limited or marginal significance. The exceptions within this cluster are Opole and Silesian voivodeships. Their placement here reflects primarily their small administrative area rather than any sectoral marginality. Compact territorial units typically display more homogeneous variable profiles, which statistically increases their similarity to other small-scale regions. Importantly, both Opole and Silesian voivodeships have demonstrated notable viticultural dynamism despite their limited territorial extent, and exhibit climatic conditions comparable to Lower Silesia or Lesser Poland.

Overall, this tripartite structure corroborates the earlier discussion on geographical concentration while revealing a clear hierarchical pattern: a strong sectoral core (Cluster 1), complemented by an emerging southeastern periphery (Subcarpathian, Lublin) positioned for potential future expansion.

4.3. Farm Size and Productivity across Provinces

Figure 6 illustrates notable regional differences in average vineyard size across Poland. Western provinces tend to have larger vineyard holdings, while southeastern regions (particularly Lesser Poland and Lublin) are dominated by smaller vineyards. These structural differences, reflecting distinct entrepreneurial strategies, are closely linked to productivity levels: western vineyards generally achieve higher yields (hectolitres per hectare) than their southeastern counterparts.

The contrast is particularly pronounced between Lower Silesia and Lesser Poland, the two provinces with the largest vineyard areas, where the former reports more than twice the productivity of the latter. This scale effect was confirmed through correlation analysis, which revealed a strong and statistically significant association between average vineyard size and regional wine output ($\rho = 0.718$, $p = .002$).

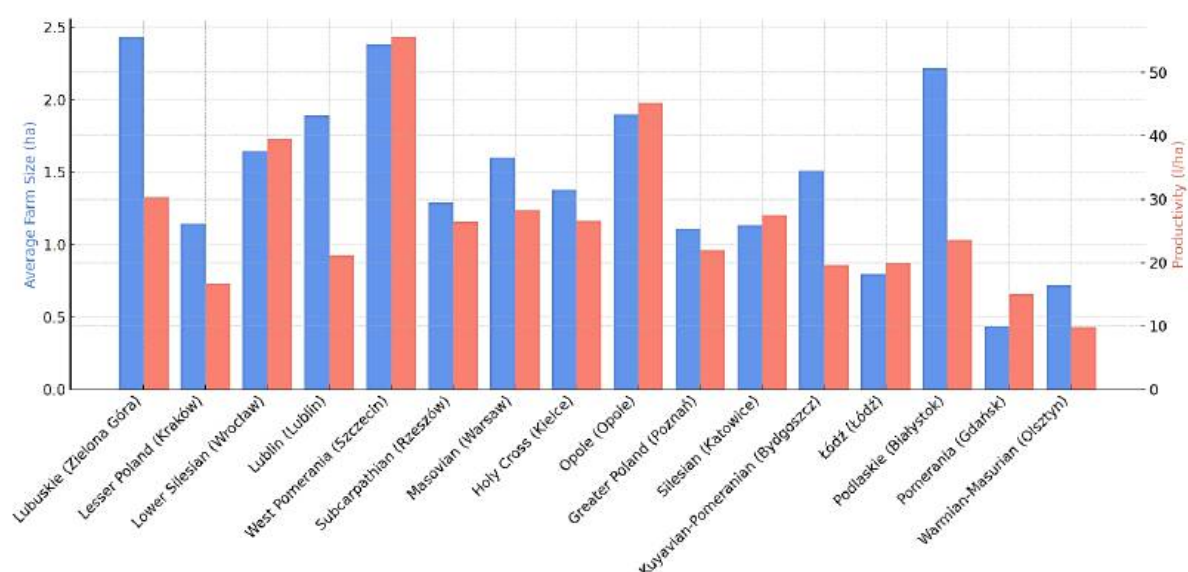


Figure 6. Average Farm Size and Wine Productivity by Voivodeship (2024).

Source: Authors' own elaboration based on data from the National Support Centre for Agriculture (KOWR), letter ref. CEN.BDG.WBI.0144.208.2024.KRU.22, dated 11 December 2024.

Moreover, provinces not traditionally associated with viticulture, such as Podlaskie Pomeranian, Łódź and Kuyavian-Pomeranian, display low productivity levels, likely due to less favourable climatic conditions, including lower sums of active temperatures (SAT) and reduced sunlight exposure (Maciejczak, Mikiciuk, 2018).

4.4. Varietal Landscape

Poland's varietal landscape is strikingly diverse. As of 5 December 2024, growers were cultivating approximately 250 grape varieties on just 990.78 hectares. This breadth reflects both the sector's youth, with producers still exploring which cultivars best suit their micro-regions, and the experimental mindset of winemakers drawn to distinctive, often unconventional grapes.

Despite this 'long tail,' a moderate degree of concentration is already evident: the five most common varieties account for roughly 41% of the national vineyard area, while the top fifteen cover 79.3%. In contrast, more than 230 other cultivars are each planted on less than 1% of the total area, highlighting the exploratory and experimental nature of Poland's wine industry (see Table 1).

Table 1.

Top 20 Grape Varieties Cultivated in Poland (December 5, 2024)

Rank	Variety	Colour	Type	Area (ha)	Share (%)
1	Solaris	White	PIWI	135,62	13,7
2	Riesling ^a	White	<i>v. vinifera</i>	80,71	8,1
3	Regent	Red	PIWI	73,53	7,4
4	Pinot Noir	Red	<i>v. vinifera</i>	59,01	6,0
5	Johanniter	White	PIWI	57,53	5,8
6	Souvignier Gris	White	PIWI	57,09	5,8
7	Seyval Blanc	White	PIWI	54,75	5,5
8	Chardonnay	White	<i>v. vinifera</i>	50,71	5,1

Cont. table 1.

9	Cabernet Cortis	Red	PIWI	48,99	4,9
10	Muscaris	White	PIWI	45,6	4,6
11	Hibernal	White	PIWI	32,6	3,3
12	Rondo	Red	PIWI	31,36	3,2
13	Leon Millot	Red	PIWI	20,93	2,1
14	Gewürztraminer/Traminer ^b	White	<i>v. vinifera</i>	19,9	2
15	Maréchal Foch	Red	PIWI	18,06	1,8
16	Zweigelt	Red	<i>v. vinifera</i>	16,99	1,7
17	Pinot Blanc	White	<i>v. vinifera</i>	15,21	1,5
18	Pinot Gris	White	<i>v. vinifera</i>	14,6	1,5
19	Dornfelder	Red	<i>v. vinifera</i>	7,39	0,7
20	Bianca	White	PIWI	7,02	0,7
—	Other Varieties	Mixed	Mixed	143,18	14,6
	TOTAL			990,78	100

Note. Data obtained from the Polish National Agricultural Support Centre (KOWR) in response to a public-information request under the Polish Access to Public Information Act, received 11 December 2024 (case ref. CEN.BDG.WBL.0144.208.2024.KRU.22).

^a Combined entry for *Riesling*, *Rheinriesling*, *Riesling Reński* and *Weisser/Weißer Riesling*.

^b Combined entry for *Gewürztraminer*, *Traminer* and *Roter Traminer*.

Table 1 reveals a clear structural pattern. Among Poland's twenty most widely planted grape varieties, twelve are white and twelve are PIWI hybrids, together accounting for 571.34 ha and 583.08 ha, respectively. Solaris, a white PIWI cultivar, leads the list, followed by Riesling, while Pinot Noir is the only red *V. vinifera* to appear in the top twenty. This distribution reflects cool-climate realities: whites ripen more reliably with lower heat accumulation, while PIWI hybrids offer disease and frost resistance crucial for Poland's marginal conditions.

4.5. Regional Patterns in Varietal Selection

Correlation analysis at the voivodeship level ($n = 16$) revealed distinct regional patterns in Polish viticulture concerning varietal composition, productivity, and the number of registered vine growers. These findings point to divergent regional strategies within the national wine sector.

Beyond the previously described positive association between average vineyard size and productivity, a significant positive correlation was observed between vineyard size and the share of individual *V. vinifera* cultivars in total vineyard area. The share of Pinot Noir correlated positively and moderately with average vineyard size in the region ($\rho = 0.509$, $p = .046$). Furthermore, Pinot Noir was positively correlated with both Chardonnay ($\rho = 0.503$, $p = .049$) and Riesling ($\rho = 0.503$, $p = .049$). The share of Riesling was also positively correlated with the number of vine growers in the province ($\rho = 0.541$, $p = .033$).

Solaris, on the other hand, was negatively correlated with the share of vineyards in agricultural land ($\rho = -0.581$, $p = .018$), indicating that regions where viticulture represents a larger share of farmland tend to have a lower prevalence of Solaris – the most widespread hybrid cultivar.

The shares of *V. vinifera* and hybrid (PIWI) cultivars tended to correlate negatively across provinces, suggesting a form of varietal ‘repulsion’ between these two groups. In particular, the share of the widely planted hybrid Solaris was negatively correlated with Riesling ($\rho = -0.585$, $p = .019$), Chardonnay ($\rho = -0.526$, $p = .038$), and Pinot Noir ($\rho = -0.556$, $p = .028$). Similarly, the share of Regent correlated strongly and negatively with Chardonnay ($\rho = -0.668$, $p = .006$), while Seyval Blanc showed a negative association with Riesling ($\rho = -0.565$, $p = .025$).

In contrast, the share of Souvignier Gris was positively correlated with other hybrids, namely Cabernet Cortis ($\rho = 0.606$, $p = .015$) and Johanniter ($\rho = 0.662$, $p = .007$), while Cabernet Cortis was also positively correlated with Johanniter ($\rho = 0.597$, $p = .017$). Johanniter’s share additionally showed a positive correlation with the number of growers ($\rho = 0.512$, $p = .045$).

This pattern indicates that regions specializing in traditional *V. vinifera* varieties are less likely to allocate significant vineyard areas to resistant hybrids, and vice versa. Regions characterized by larger average vineyard holdings and a higher concentration of vineyards tend to provide more favourable conditions for the cultivation of premium *V. vinifera* varieties, while smaller- scale operations appear to favour disease-resistant hybrid cultivars as a risk-mitigation strategy.

To assess regional differences in varietal strategy, we calculated an Innovation Ratio defined as the proportion of vineyard area planted with varieties outside the ten most popular cultivars nationally. This indicator captures the extent to which regional producers experiment with less mainstream varieties versus concentrating on established cultivars. We then examined correlations between this Innovation Ratio and regional productivity (hectolitres per hectare).

The Innovation Ratio exhibited substantial regional variation, ranging from 15.95% in Opole, 22.45% in West Pomeranian, and 25.38% in Greater Poland, to 51.37% in Pomeranian, 44.31% in Podlaskie, and 40.67% in Warmian-Masurian. A statistically significant negative correlation was observed between Innovation Ratio and productivity ($\rho = -0.56$, $p = .024$), indicating that regions with greater varietal experimentation achieve lower yields per hectare. Notably, our analysis revealed that climatically marginal regions demonstrate higher propensity for varietal experimentation, suggesting a strategic trade-off between productive efficiency and adaptive exploration.

5. Discussion

5.1. Key Empirical Findings

Polish viticulture has experienced remarkable growth: the number of winegrowers, vineyard area, and production have all increased several-fold over the past decade. Polish vineyards host more than 250 grape varieties, both PIWI and *vinifera*, demonstrating extraordinary varietal diversity. Simultaneously, a clear concentration exists, with the top fifteen varieties accounting for nearly 80% of plantings, including PIWI hybrids, shows that growers balance innovation with strategic pragmatism.

One of the most important findings is the pronounced regional differentiation of Polish viticulture. The country's three climatic wine regions align closely with long-standing historical, social, and cultural divisions. It is therefore increasingly difficult to speak of 'Polish wine' as a homogeneous national category; rather, the sector must be understood as a regionally differentiated phenomenon. The western provinces (Region I) are characterized by larger farms, higher productivity, and an emphasis on international *V. vinifera* varieties such as Riesling and Pinot Noir. By contrast, the southeastern provinces (Region II) feature smaller farms, lower yields, but greater varietal experimentation. Beyond these two main wine regions, viticultural enterprises also operate in the remaining parts of the country (Region III), characterized by the harshest climatic constraints.

5.2. Interpretation

To interpret these patterns, we apply Uchnast's (1997) concept of personal resilience – the capacity to thrive and survive under stressful conditions while preserving one's identity. Uchnast distinguishes between high resilience (accepting risk, abandoning routine, openness to novelty) and low resilience or 'security syndrome' (prioritizing stability, clinging to status quo). This framework may illuminate why Polish viticulture thrives despite marginal conditions, suggesting that vineyard establishment requires particularly high personal resilience.

One might assume that Polish winemakers, representing this pioneering industry, generally exhibit high personal resilience: openness to new experiences, risk acceptance, departure from routine, and readiness for failure. However, given the heterogeneous nature of Polish viticulture documented above, it is worth considering whether winemakers across the three regions might vary in their resilience profiles.

This analysis suggests that it is reasonable to propose research hypotheses about different personality patterns among winemakers in Regions I, II, and III. Region I, with its relatively long, albeit interrupted, winemaking tradition and benefiting from proximity to German viticulture providing organizational support and know-how, represents a more stable and predictable environment for winemakers than Region II, which is building its identity from scratch. Consequently, winemakers in the southeastern region may be characterized by higher

levels of strategic experimentation, risk acceptance, bricolage, and, perhaps, overall personal resilience than their counterparts in western Poland. The prevalence of PIWI cultivars, particularly Solaris, consistently a safe choice in northern climates – may represent situational awareness rather than lack of innovation, both key components of resilience. We can hypothesize that Region III winemakers exhibit even higher risk acceptance and bricolage, alongside a particularly deep sense of meaning in their enterprise, as they persist despite operating in areas largely unfavourable for viticulture.

Northern and northeastern provinces exhibit significantly higher Innovation Ratios, reflecting greater willingness to experiment with non-mainstream cultivars, which correlates negatively with productivity. This readiness to cultivate less popular and potentially less productive varieties supports the thesis that viticulture and wine production in these marginal regions are motivated primarily by non-economic factors.

These findings reinforce our argument that personal resilience and meaning-making may be key to understanding entrepreneurial persistence in climatically challenging viticultural environments. The observed regional differentiation also reflects organizational ambidexterity at sectoral level: western regions seem to prioritise exploitation, concentrating on proven *vinifera* cultivars to maximize efficiency, while marginal regions emphasize exploration through varietal experimentation (March, 1991; Zakrzewska-Bielawska, 2016).

The persistence of viticulture, especially in the most difficult regions, may be additionally illuminated through Frankl's concept of meaning-making. According to Frankl, individuals derive meaning through creative values (what they contribute), experiential values (what they receive), and attitudinal values – how they respond to unchangeable circumstances (Uemura, 2018). Winemaking and viticulture (which, after all, go hand in hand among most small producers) manifest both creative and attitudinal values: the winemaker creates and shares their product with the world, while demonstrating resilience in the face of hardship and turbulence. Experiential values find their manifestation in the mutual support that winemakers offer one another. No single strategy suits all enterprises; effective strategic choices must be tailored to the specific characteristics of the industry and market context, as well as organizational resources and capabilities (Romanowska, 2016).

We believe that this framework, which integrates wine industry analysis with resilience theory and meaning-making processes, can enrich academic discourse on viticulture with a significant psychological component that may prove crucial for winemaking in emerging wine countries.

5.3. Policy and Practical Implications

From a policy-making standpoint, Polish authorities should acknowledge the pronounced regional heterogeneity documented in this study when designing support instruments for the wine sector. The emerging wine clusters identified in our data could form nuclei for future appellation systems; therefore, sectoral statistics and development programs should be

organized around these clusters rather than administrative voivodeship boundaries. The widespread adoption of PIWI cultivars, resistant to common fungal diseases, may serve as a foundation for sustainable, low-input agricultural models in Poland's emerging wine regions. This trend should be reflected in support policies and strategic frameworks that recognize the environmental and economic benefits of disease-resistant varieties in marginal climatic conditions.

5.4. Limitations and Directions for Future Research

A principal limitation of this study is that all registry data were aggregated at the level of Poland's 16 administrative provinces. This constrains both the spatial precision of the analysis and the ability to identify truly emergent wine regions. Future research should therefore aim to generate more granular data: both at the level of emerging terroir-based micro-regions and at the level of individual wineries and vineyards.

A more robust dataset covering specific enterprises would also help address the statistical limitations noted earlier, such as the small number of regional observations and the potential non-normality of key variables. Fine-grained data would allow for more reliable inferential analysis and better model specification.

These findings also point to broader questions that merit future investigation. One promising line of inquiry concerns the extent to which Poland's emerging wine clusters coincide with deeper socio-cultural cleavages across regions – differences shaped by historical legacies and reflected in patterns of religiosity, political affiliation, or family structures. Another research avenue involves examining how winemakers' personal motivations, value systems, and resilience-related traits influence their strategic decisions regarding enterprise scale, varietal selection, and market orientation.

While the present paper is exploratory in nature and does not aim to test such relationships using psychometric tools, we believe that assessing the personal resilience of winemakers and growers in different parts of the country – and directly studying their motivations for launching and continuing winegrowing activities under challenging conditions – offers a highly promising direction for future research, potentially with a cross-national comparative component.

6. Conclusion

Polish viticulture and wine production has experienced remarkable growth over the past decade, expanding from a niche industry growing from 134 to 990 hectares between 2014 and 2024, with production increasing from 2737 to 27,974 hectolitres over the same period. Wine production concentrates primarily in two regions (western belt and southeast), which exhibit significant differences in average vineyard size, productivity, and varietal selection.

Polish vineyards host more than 250 grape varieties, both PIWI and vinifera, but the top 15 varieties account for 79.3% of total plantings.

The study shows that Polish winemaking is inherently heterogeneous: two dominant models can be observed, one drawing from German solutions and the other seeking its own path. At the same time, the wine industry in Poland is still young and, in its early stages, continues to experiment—particularly with varietal selection. Furthermore, the study reveals that the pursuit of profit is not the only driving force behind the industry's development and that non-economic factors play a noteworthy role in winemaking.

Our exploratory study represents the first attempt to explain the development of winemaking in a marginal climate region, particularly entrepreneurial decision-making in the wine sector, through the prism of resilience and demonstrating how significant non-economic motivations can be in such analyses.

In terms of practical implications, we demonstrate that there is solid ground for potential future applications. We suggest that due to the heterogeneous nature of Polish viticulture, there is a necessity for regionally differentiated policies. We recommend deeper study of PIWI varieties as a foundation for sustainable agriculture. We also suggest that given the wide range of producer sizes and the large number of small producers, policymakers should pay special attention to small wine farmers, who in many areas are the backbone of Poland's wine industry.

This study is intended as a foundation for subsequent psychometric investigations examining how personality traits influence and moderate strategic decision-making across different wine regions. We suggest cross-national studies with other emerging wine countries, quantitative research utilizing personal resilience measurement scales, and qualitative studies on personality traits of vine growers and producers.

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INNOVATIONS IN THE POLISH OFFSET PRINTING INDUSTRY – A KEY IN BUILDING COMPETITIVE ADVANTAGE IN THE DIGITAL ERA

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Purpose: To examine how innovations implemented by Polish offset printing companies contribute to building competitive advantage in the digital era. The study identifies which innovation types (product, process, marketing, organizational), degrees of novelty, and firm/market characteristics most strongly relate to competitiveness outcomes.

Design/methodology/approach: A nationwide survey of 123 offset printing companies (Poland) was conducted; 85 reported implementing innovations in the past three years. The analysis combines descriptive statistics with non-parametric tests (Mann-Whitney U; Kruskal-Wallis) to assess links between innovation types/novelty and competitiveness benefits across domestic vs. international markets.

Findings: Innovation adoption is shaped by both internal factors (firm size, machine park, print format, age) and external reach (national/international/global markets). Product and marketing innovations show the strongest association with competitiveness—increasing assortment, enabling entry into new markets, and supporting supply-chain optimization—particularly in international markets. Younger firms and those operating at larger scales are more likely to innovate; process and organizational innovations yield operational gains, with competitiveness effects emerging mainly at higher novelty levels.

Research limitations/implications: Results rely on self-reported, cross-sectional data from one country and lack external performance indicators. Future longitudinal and multi-country studies, complemented by qualitative evidence, should validate causality and benchmark objective outcomes. For practitioners, strategic innovation management should prioritize product/market-facing changes while sequencing process/organizational upgrades to amplify competitiveness gains.

Originality/value: This is among the first empirical studies to map the structure, novelty, and effects of innovations in Polish offset printing, disentangling how internal/external conditions and innovation type relate to measurable competitive outcomes in a sector navigating digital transformation.

Keywords: Offset printing, innovation, competitive advantage, digital transformation, Poland, product/marketing innovation, internationalization.

Category of the paper: Research article.

1. Introduction

The Polish printing industry has been experiencing dynamic growth over the past two decades (Cetera, 2015), making Poland an important player on global markets, with the sixth largest global market share, and export revenues exceeding PLN 7 billion, especially in relation to products requiring high-quality printing and post-press - books, children's products (Ministerstwo Rozwoju i Technologii, 2025). These products are largely characteristic of offset printing, guaranteeing very high quality and repeatability of performance.

Given its significant global market share, the development of the printing industry in Poland cannot be achieved without high-volume technologies enabling the fulfilment of very large batches of orders, for which offset printing technology remains relatively well-suited.

The offset printing sector plays a significant role in Poland's industrial structure, providing packaging crucial to key branches such as the food and pharmaceutical industries, which together represent a major share of national industrial output. This is because replacing offset printing with digital printing in packaging production is still an incomplete and slow process, characteristic rather for smaller packaging, such as textile labels (Yilmaz, Cavus, 2018).

Maintaining and developing this industry is also important due to its significance for the automation of trade, transport, and logistics, as it enables the cost-effective production of labels and barcodes read by robots in very large quantities as part of modern sorting, warehousing, and transshipment processes. This applies in particular to RFID tags, which impact the profitability of automation processes because they are much cheaper than chips and transponders (Lopez-Iturri et al., 2023).

The printing industry is undergoing intense technological and organizational transformations. These changes are primarily driven by digital transformation (Merritt, Vilchis-Flores, 2024), which is altering the structure of the industry and leading to the growing popularity of digital printing and 3D printing. At the same time, another driving force behind these changes is regulatory pressure to gradually reduce waste and replace chemicals traditionally used in printing (Reese et al., 2020).

Despite the dynamic changes, scientific knowledge regarding the structure of innovation in the offset printing sector and its impact on business competitiveness remains limited. Academic literature is dominated by technical studies (Tuğrul, 2024; Strižić Jakovljević et al., 2024; Owsiński et al., 2024).

Innovation in the offset printing sector is driven i.a. by the cross-sector competition from the digital printing sector (Burge et al., 2012; Viluksela et al., 2010). Internal sector pressure, on the other hand, is limited by numerous technological and cost-related entry barriers (Burge et al., 2012; Merritt, Vilchis-Flores, 2024).

The offset printing sector is undergoing transformation primarily in two key areas, accompanied by significant structural changes (Merritt, Vilchis-Flores, 2024; Magadán-Díaz and Rivas-García, 2021; Salwin et al., 2020):

1. a shift from a product-focused to a product-service model in supplier relations, with machinery increasingly offered via leasing rather than sale (Salwin et al., 2020),
2. development of hybrid business models that merge traditional offset methods with innovative technologies linked to digital transformation (Magadán-Díaz, Rivas-García, 2021).

The above confirms that the offset printing industry's contemporary development is generally consistent with the diffusion of innovation theory. The spread of digital and hybrid solutions in this industry reflects typical adoption patterns shaped by perceived relative advantage, compatibility with existing practices (e.g. business models), and external pressure (regulation and cross-sector competition). However, there has probably been no study to date that has clearly assessed observations in the offset printing sector in the context of innovation theory.

In particular, there is a need to assess the functioning of this industry in the context of specific models of innovation development. The three-factor model of innovation development accurately reflects the situation of small and medium-sized enterprises in Poland and can serve as the basis for building a theoretical model for research in the Polish offset printing sector. The three-factor model of innovation development assumes that the benefits of innovation lead to the development of the propensity to innovate, while the propensity and ability to innovate determine the development of innovation (Stanisławski, 2020).

The aim of this article is to assess how innovations implemented by Polish offset printing companies contribute to building their competitive advantage in the era of digital transformation in the industry. The article analyses the structure and scale of implemented innovations—including new or significantly modified product, process, marketing, and organizational solutions—and evaluates their impact on operational efficiency, product offering development, and market expansion.

The scientific findings of the paper will be presented in the context of the main theories of innovation and the three-factor model of innovative development.

3. Innovation, Competitiveness, and Digital Transformation in the Offset Printing Industry

3.1. Key Concepts and Definitions

Innovation is the driving force behind effective management and plays a key role in the development of an enterprise. It is a fundamental factor in competitive advantage, technological progress, and sustainable development. Innovation significantly impacts the transformation of companies by optimizing costs and supporting ecological progress. According to definitions that emphasize innovation as a process, novelty and transformation of reality are usually the indicators of whether a given process constitutes an innovation, and based on their outcomes, the scope of the innovation can be determined (Yeremenko, Rudskaya, 2016). According to the Oslo Manual (2018), innovation is a new or significantly improved product or process (or a combination of both) that differs from previous versions and is made available to users or implemented in practice. The manual divides innovation into four types: product innovation, process innovation, organizational innovation, and marketing innovation (OECD/Eurostat, 2018).

A further classification of innovation can be made based on its impact and degree of novelty. Innovations are often described as radical or incremental. Radical innovations result in breakthrough changes that can completely transform existing markets or create entirely new ones, while incremental innovations involve minor improvements or adjustments to existing products or processes (Cabigiosu, Campagnolo, 2016; Garcia, Calantone, 2002).

Innovation is closely linked to a company's competitiveness. Competitiveness is a concept derived from the theory of competitive advantage, which assumes that to survive in a competitive market, companies must offer a unique value proposition and strategy that ultimately allows them to outperform rivals (Lee, Karpova, 2018). There is no single, universally accepted definition of competitiveness (Dzikowska, Gorynia, 2012). Most broadly, competitiveness can be defined as the ability to compete with other market players (Pavliuk, Noda, 2020).

Competitiveness depends on both external and internal factors. External factors include access to technology (Amadasun, Mutezo, 2022), partnerships formed to access such technology (Lahiri, Narayanan, 2013), the overall innovativeness of the its macroeconomic stability (Yu, 2023), appropriate state fiscal policy (Jabłońska-Porzuczek, Smoluk-Sikorska, 2016), and access to infrastructure, trade efficiency and national economic specialization (Lee, Karpova, 2018). Other external factors include the ability of a sector or geographic region to attract people and capital (Čučković et al., 2013).

Internal factors of competitiveness include strategic leadership (Oracha et al., 2021), efficiency in resource management (Purwohandoko, 2018), including knowledge resources (Ma et al., 2019), flexibility in responding to market needs (Games, Roliza, 2019), strategic

planning abilities related to resource provision and use (Davcik, Sharma, 2016), organizational culture (Naidoo, Sutherland, 2016), the ability to adapt to consumer demands (Tumalanov et al., 2017), as well as company image (Zhan-Hui et al., 2011) and effective brand management (Qureshi et al., 2022).

Competitiveness is closely linked to innovation capability, innovation willingness, and the external environment, which together form a three-factor model of innovation development that supports long-term competitive advantage of the enterprise (Stanisławski, 2015). In increasingly competitive markets, innovation gains importance as it enables firms to outperform rivals and adapt to market changes (Distanont, Khongmalai, 2018).

Another important factor influencing the level of competitiveness is digital transformation (Härting et al., 2020), that includes, in particular, the implementation of modern IT tools (artificial intelligence, Internet of Things (IoT), process automation, cloud computing, data analysis, and others), as well as the adaptation of organizations to these technologies (Antczak, Kos, 2022), requiring continuous changes in the mindset of decision-makers and structures (Azieva, 2021). It is not limited to operational improvements; but includes redefining business models, enhancing customer experiences (Cennamo et al., 2020), and adapting organizational culture, regulatory frameworks, and service delivery mechanisms (Manny et al., 2021).

Only the companies that successfully implement digital transformation strategies can increase their operational efficiency and adaptability in fast-changing markets (Yao et al., 2023; Takriti, 2023). The greater their capabilities in implementing information and communication technologies, the better they translate digital transformation into innovation (Zhu, 2024).

Key factors of digital transformation include access to technology (Antczak, Kos, 2022), qualified employees (Xin et al., 2022), cooperation with external entities (Li et al., 2017), and awareness of the cybersecurity (Antczak, Kos, 2022).

The transformation of the printing industry has so far been studied in the context of several theories of innovative development.

Schumpeterian innovation theory posits that economic development is driven by innovations introduced by entrepreneurs, which lead to "creative destruction"—the displacement of old technologies by new ones, which in turn generates increased productivity and profitability (Ülgen, 2013). Neo-Schumpeterian and systems-based approaches, on the other hand, assume that innovations arise from cumulative learning processes as well as the collaboration between companies or other stakeholders (research institutions, states), and that their effectiveness depends on the quality of the innovation system and the organization's ability to absorb the knowledge (Urmetzer et al., 2018). These findings are broadly complemented by E. Rogers's theory of innovation diffusion. According to this theory, the dissemination of specific solutions depends on their advantages over existing solutions, compatibility, complexity, testability, and observability of effects (Mohammadi, 2018).

The printing industry has, in many empirical observations, to some extent eluded older theories of innovation. The first stage of development of the printing industry, associated with the invention of the printing press, challenges Schumpeterian innovation theory because it did not lead to an increase in productivity or per capita income, despite being technologically groundbreaking. The second stage, associated with automation and job reduction, is inconsistent with neo-Schumpeterian and systemic theories of innovation, which assume broad social and organizational benefits resulting from innovation, whereas the observable effect of technological change in this industry is a decline in employment and related business costs (Chungu, 2024).

3.2. Technological and organizational transformations in the offset printing sector

The global printing industry is experiencing significant changes, particularly related to digital transformation, especially the shift from generic offset to digital printing, which is generally faster, more cost-effective, environmentally friendly, and operationally simpler due to minimal machine reconfiguration, lower energy use, and reduced waste (Mirković, 2024).

However, a substantial part of the printing industry continues to rely on offset technology, as it remains profitable for larger production runs and offers excellent detail quality, difficult to maintain in long digital print runs (Vukoje et al., 2021; Spiridonov et al., 2020), which is particularly important for art printing and packaging (Jakovljević, 2024).

Despite the seemingly declining nature of the technology, process innovations in offset printing continue to develop intensively (Hauck, 2015). Despite the lack of transition to digital printing, offset companies are also undergoing a digital transformation that involves supplementing traditional models with online sales and digital distribution, allowing firms to expand their customer base and sustain long-run orders as well as automating the design, production, invoicing, and delivery processes to reduce digital printing's speed advantage (Magadán-Díaz, Rivas-García, 2021).

Digitization in offset printing relies on data (Salwin, 2020), particularly through the implementation of IoT solutions (Meissner, 2021). Moreover, while industrial automation supports the competitiveness of offset printing companies, offset printing itself remains essential to the adoption of automation in other industries by delivering diverse printed solutions, for example, labels read by robots (Perera et al., 2021; Kerndl, Šteffan, 2020).

Against the backdrop of the above review of existing knowledge, many uncertainties and questions remain, creating a cognitive gap.

Although digital transformation, process automation, and business model changes in the offset printing sector are widely seen as factors that enhance competitiveness, there is a lack of systematic, empirical research that definitively quantifies the impact of specific types of innovation (product, process, marketing, organizational) on the competitiveness of these companies. In particular, it is unclear which innovations generate the greatest benefits in both domestic and international markets, or to what extent differences in innovation scale affect

companies' ability to maintain competitive positions in a rapidly changing business environment.

Research further suggests that the implementation of innovations by printing companies depends on both internal and external conditions (Magadán-Díaz, Rivas-García, 2021), yet these factors are not systematically analysed. Relational resources—shaped by structural characteristics and the business environment—are likely to be significant innovation drivers (Salwin et al., 2020), but it remains an open question which specific internal and external factors measurably influence innovation development in this sector. This issue is particularly important for management theory, as some authors believe that the propensity for innovation is directly tied to company size (Codogini et al., 2013). If so, innovation should be most strongly linked to structural factors in sectors where innovation capacity is also likely to depend heavily on market position (Salwin et al., 2020). On the other hand, innovations are also the driving force behind small and medium-sized enterprises, which themselves drive the entire economy (Stanisławski, 2022). Therefore, innovations should be accessible to individual entities regardless of their structural characteristics.

Moreover, while printing companies acknowledge that digital transformation brings performance benefits, little research exists on how these initial gains drive further innovation adoption. In other words, it is unclear whether innovation-based growth models in the offset printing industry are sufficient to ensure lasting competitiveness—or whether these are simply transitional adaptations buying time before a shift to digital printing. It is also uncertain whether offset printing companies are truly innovation-driven, and whether those that successfully implement innovations are more likely to seek additional novel solutions. This represents an important research gap, as management theory strongly suggests that the willingness to innovate is closely linked—if not equivalent—to the perception of innovation benefits (Stanisławski, 2015). The printing sector should not deviate from this paradigm, yet empirical studies on this are lacking.

Identified Research Hypotheses Corresponding to the Cognitive Gap:

- H0: Innovations implemented in the past three years have a positive impact on the competitiveness of offset printing companies in Poland.
- H1: Innovations implemented by offset printing companies in Poland vary in terms of type (scope) and degree of novelty.
- H2: The level of innovation implementation depends on internal conditions of offset printing companies—such as structural characteristics, areas of activity, and experience—as well as external conditions, such as the markets in which they operate.
- H3: Implemented innovations directly influence the willingness (benefits) of offset printing companies to adopt further novel solutions.

H4: The benefits generated depend on the type (and degree) of innovation introduced—product and marketing innovations generate the most significant advantages compared to process or organizational innovations.

H5: Improved competitiveness of offset printing companies is the most important benefit achieved in both domestic and international markets.

To better illustrate the impact of innovation in Polish offset printing companies, a model was created for the given hypotheses (see Figure 1).

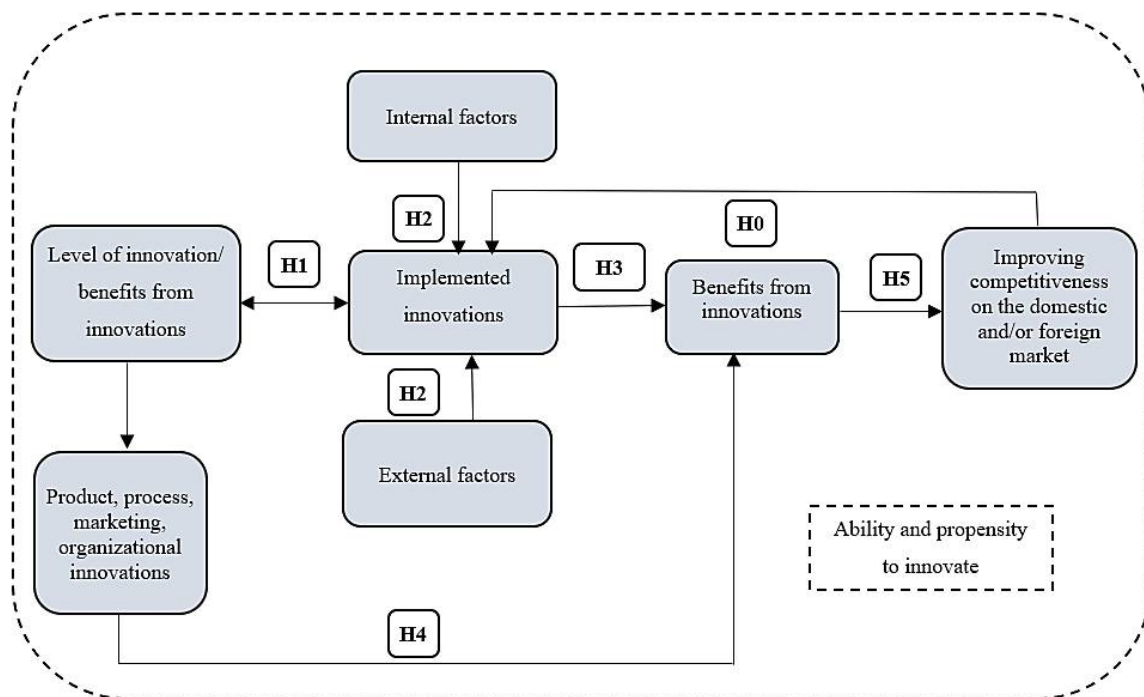


Figure 1. A model to the given hypotheses.

Source: Author's own research.

4. Research methods

4.1. Subject and method of study

The population in this study consists of offset printing companies operating in Poland, equipped with at least one offset printing machine. The data collection was conducted through an online survey from March to May 2023. Responses were obtained from 123 representatives of offset printing companies, which constitutes a representative sample of the studied population (Table 1).

Table 1.
Description of the research group

Distribution of responses	
Factor	All companies (including those that did not introduce innovations)
Company size	
Micro	9 (7.3%)
Small	60 (48.8%)
Medium	49 (39.8%)
Large	5 (4.1%)
Dominant market	
Global	7 (5.7%)
National	42 (34.1%)
International	53 (43.1%)
Regional	20 (16.3%)
Local	1 (0.8%)
Dominant printing profile (focus sector)	
Books / magazines / art	24 (19.5%)
Label (including in mould labeling - IML)	6 (4.9%)
Forms / personalization	4 (3.3%)
Packaging (food and non-food)	32 (26%)
Advertising	56 (45.5%)
Gazette	1 (0.8%)
Number of offset print machines	
1-2	72 (58.5%)
3-4	31 (25.2%)
5-6	81 (4.6%)
7 and more	(1.6%)

Source: Author's own research.

4.2. Statistical Methods

The analysis employed statistical methods to describe the distribution of responses and the structural characteristics of entities. The Mann-Whitney U test (Mann, Whitney, 1947), a semiparametric test, was used to determine intergroup differences. The jamovi project® software (2024) facilitated hypothesis testing using data from 85 enterprises that had implemented innovations.

The criteria for assessing competitiveness improvements included:

1. Expanded range of printing products and services.
2. Entry into new markets or increased market share.
3. Reduced production/labour costs.
4. Improved product quality/reduction in complaints.
5. Time-related process improvements.
6. Enhanced work/production efficiency.

7. Lower unit prices for customers.
8. Increased printing order volumes.
9. Supply chain optimization.
10. Broader range of additional services.
11. Development of online ordering platforms.

Additionally, the impact of innovations on key benefits over the past three years was explored. Cross-group differences were measured using the Mann-Whitney U test for the following industry-specific categories:

1. Employee skill and competence enhancement.
2. Improved financial performance.
3. Reduction in complaints from printing/finishing processes.
4. Establishment of new industry relationships.
5. Compliance with standards and regulations (e.g., FOGRA, FSC, BRC).
6. Reduced environmental impact.
7. Enhanced competitiveness.
8. Improved company image.
9. Increased stability.
10. Faster order fulfilment.
11. Geographical proximity to customers.
12. Digitalization of business processes.
13. E-commerce and online sales development.
14. Increased security of data/graphic files.
15. Other benefits.

5. Results and discussion

5.1. Sample description

123 responses were obtained from Polish companies in the offset printing industry. 85 of them (69.1%) implemented innovations in the last three years, while 38 (30.9%) did not (Table 2). Data came from all seventeen regions of the country and were relatively evenly distributed geographically.

Table 2.*Percentage of companies that have introduced innovations in the last three years*

Yes		NO		Together	
Number of replies	%	Number of replies	%	Number of replies	%
85	69.11%	38	30.89%	123	100%

Source: Author's own research.

Most innovative companies in the Polish offset printing sector are medium-sized (54.1%) or small (36.5%) enterprises. Notably, medium-sized firms are disproportionately represented among innovators (54.1%) compared to the general sample (39.8%). In contrast, innovations are less frequently implemented in small enterprises (36.5% vs. 48.8%) and microenterprises (3.5% vs. 7.3%). Innovative firms are predominantly located in metropolitan areas or provincial capitals (40%) and larger cities with populations exceeding 100,000 (22.35%). This urban concentration is more pronounced among innovators (40%) compared to the overall sample (35.8%).

Most innovative companies operate in international (57.65%) or national (30.59%) markets, with minimal focus on regional or local markets.

Innovators are more engaged in packaging printing compared to the general sample (37.7% vs. 26%) but are less involved in print advertising (29.4% vs. 45.5%).

The production infrastructure of printing houses highlights the number and types of machines as key structural features. Companies with 1-2 offset machines represent the largest group among innovators (45.88%), followed by those with 3-4 machines (31.76%). Fewer firms operate with five or more machines, although innovators generally have larger machine parks. For example, 22.4% of innovators operate five or more offset presses, compared to just 6.2% of the general sample.

A significant structural factor in the studied industry is undoubtedly the ability to produce large-format prints. In this regard, it is clear that innovative companies tend to prefer large formats. The B1 format, used by 57.65% of innovators, the B0 format, found in 7.06% of innovators, supports even larger sheet sizes. the B2 format, used by 23.53% of innovators, is the second most popular and is associated with medium-sized productions, such as brochures, catalogues, or books. Smaller formats, including A1 (5.88%), A2 (2.35%), and B3 (3.54%), are used less frequently.

It is also clear that the lack of innovation is related to smaller formats. For instance, 57.7% of innovators use the B1 format compared to 43.9% of the general sample.

Table 3.*Structural characteristics of the study group, including companies that introduced innovations*

Distribution of responses	
Factor	Companies that introduced innovations
Company size	
Micro	3 (3.5%)
Small	31 (36.5%)
Medium	46 (54.1%)
Large	5 (5.9%)
Company location	
Rural area	4 (4.7%)
Small town (to 20,000 inhabitants)	9 (10.6%)
Medium town (20,001 to 100,000 inhabitants)	19 (22.4%)
City (above 100,001 inhabitants)	19 (22.4%)
Large city agglomeration/regional capital	34 (40.0%)
Dominant market	
Global	7 (8.2%)
National	26 (30.6%)
International	49 (57.7%)
Regional	3 (3.5%)
Local	-
Dominant printing profile (focus sector)	
Books / magazines / art	20 (23.53%)
Label (including in mould labeling - IML)	6 (7.06%)
Forms / personalization	2 (2.35%)
Packaging (food and non-food)	32 (37.65%)
Advertising	25 (29.41%)
Newspaper	-
Number of offset print machines	
1-2	39 (45.88%)
3-4	27 (31.76%)
5-6	17 (20.00%)
7 and more	2 (2.35%)
Dominant print format	
A1	5 (5.88%)
A2	2 (2.35%)
B0	6 (7.06%)
B1	49 (57.65%)
B2	20 (23.53%)
B3	3 (3.54%)

Source: Author's own research.

5.2. Innovations in the Polish offset print sector

All four main types of innovation are prevalent in the Polish offset printing sector. Among innovative enterprises, 62.35% introduced product innovations, 57.65% process innovations, 48.24% organizational innovations, and 29.41% marketing innovations, with product innovations also adopted by over 40% of all surveyed firms (table 4).

Table 4.

Percentage of enterprises that have introduced innovations of types in the last three years

Type of innovation	Yes		NO		Together	
	Number of replies	%	Number of replies	%	Number of replies	%
Product	53	62.35%	32	37.65%	85	100%
Process	49	57.65%	36	42.35%	85	100%
Marketing	25	29.41%	60	70.59%	85	100%
Organizational	41	48.24%	44	51.76%	85	100%

Source: Author's own research.

Product innovations are most often sporadic (45.3%), with a moderate share of evolutionary (30.2%) and radical (24.5%) innovations. They most often reach a national scale (56.6%), while at the company level they constitute 36.9%. However, the surveyed entities also implemented product innovations that were new on a global scale (3.8%).

In most of the surveyed entities, these innovations had a large impact on the innovative development of the company (56.6%), with a medium impact in some cases (30.2%). A very large impact was less frequent (11.3%), and a small impact was almost negligible (1.9%).

Process innovations are most often characterized by a sporadic degree of breakthrough (44.9%), but the share of radical innovations is also significant (36.7%). The evolutionary nature of process innovations is much rarer (18.4%). In terms of the scale of innovations, those on a company scale dominate (53.1%), followed by innovations on a national scale (44.9%), while innovations on a global scale are very rare (1.9%).

The impact of process innovations on company development was most often high (57.1%), with a moderate share of cases with medium impact (26.5%). A very high impact was noted in 14.3% of cases, while a small impact was marginal (1.9%).

Marketing innovations are characterized by a relatively even distribution between evolutionary and sporadic degrees of breakthrough (31-34.5%). In terms of the scale of novelties, company-scale novelties dominate (55.2%), with a relatively large share of national-scale novelties (44.8%). However, no marketing innovations among the surveyed companies were new on a global scale. The impact on the development of the company was most often described as large (48.3%), with a smaller share of cases with medium impact (27.6%). A very large impact was observed in 20.7% of entities, while a small impact was marginal (3.4%).

Organizational innovations are characterized by a dominant share of evolutionary changes (53.7%), followed by innovations (31.7%), with the smallest share recorded for radical innovations (14.6%). In terms of the scale of novelties, organizational innovations most often occur at the company level (70.7%), while fewer are new solutions on a national scale (29.3%). No innovations with a global degree of novelty were declared in this category. Regarding their impact on company development, the largest share falls on cases with a high impact (68.3%), followed by a medium impact (22%). A very high impact accounted for 7.3%, while a small impact remains marginal at 2.4%. This is summarized in Table 5.

Table 5.

Product, process, marketing and organizational innovations by degree of breakthrough, scale of novelty and impact on company development

Factor	Scale	Product	Process	Marketing	Organizational
Degree of breakthrough	Evolutional	16 (30.2%)	9 (18.4%)	10 (34.5%)	22 (53.7%)
	Radical	13 (24.5%)	18 (36.7%)	9 (31%)	6 (14.6%)
	Occasionally	24 (45.3%)	22 (44.9%)	10 (34.5%)	13 (31.7%)
Scale of novelty	Business	21 (36.9%)	26 (53.1%)	16 (55.2%)	29 (70.7%)
	Country	30 (56.6%)	22 (44.9%)	13 (44.8%)	12 (29.3%)
	World	2 (3.8%)	1 (1.9%)	-	-
Impact on the innovative development of the company	Very big	6 (11.3%)	7 (14.3%)	6 (20.7%)	3 (7.3%)
	Big	30 (56.6%)	28 (57.1%)	14 (48.3%)	28 (68.3%)
	Mediocre	16 (30.2%)	13 (26.5%)	8 (27.6%)	9 (22%)
	Small	1 (1.9%)	1 (1.9%)	1 (3.4%)	1 (2.4%)
	Very small	-	-	-	-

Source: Author's own research.

Medium-sized companies (58.57%) are the largest group reporting tangible benefits (table 5), followed by small businesses (31.43%).

Table 6.

Percentage of enterprises that achieved measurable benefits from implemented innovations

Companies that have introduced innovations					
Yes		NO		Together	
Number of replies	%	Number of replies	%	Number of replies	%
70	82.35%	15	17.65%	85	100%

Source: Author's own research.

Companies (table 7) with 1-2 offset presses are the largest group experiencing benefits (38.57%), followed by those with 3-4 presses (34.29%). The B1 format is the most popular among companies experiencing benefits (60%), followed by B2 (20%) and B0 (8.57%).

Table 7.*Enterprises that achieved measurable benefits from implemented innovations*

Distribution of responses		
Scale	Number of replies	%
Company size		
Micro	2	2.86%
Small	22	31.43%
Mediocre	41	58.57%
Big	5	7.14%
Number of offset machines		
From 1 to 2	27	38.57%
From 3 to 4	24	34.29%
From 5 to 6	17	24.29%
7 and more	2	2.86%
Dominant print format		
A1	3	4.29%
A2	2	2.86%
B0	6	8.57%
B1	42	60.00%
B2	14	20.00%
B3	3	4.29%

Source: Author's own research.

Companies reported tangible benefits, particularly in the areas of competitiveness, financial performance, and corporate image. Moderate benefits included environmental sustainability, employee development, and digital transformation (Table 8).

Table 8.*Summary of measurable benefits resulting from implemented innovations*

Factor	No benefits	Very little benefit	Small	Mediocre	Big	A very big benefit
Raising employee qualifications and competences	3	8	16	16	20	7
Improving the company's financial situation	0	6	13	21	24	6
Reduction in the number of complaints resulting from the printing or finishing process	0	6	18	18	21	7
Establishing new relationships with industry players	3	5	12	19	25	6
Compliance with printing regulations, norms and standards (FOGRA, FSC, BRC or equivalent)	6	7	7	27	15	8
Reducing environmental impact	2	7	16	17	20	8
Improving the company's competitiveness	0	6	5	14	33	12
Improving the company's image	1	5	7	11	32	14
Increased company stability	0	3	8	16	31	12
Speed of order fulfilment	0	2	9	24	24	11
Location (distance from customer)	17	19	12	10	8	4
Digitalization of business processes	3	7	12	20	22	6

Cont. table 8.

Development of e-commerce and online sales of printed materials	10	11	3	17	22	7
Increased security of data/graphic files	8	6	11	17	15	13
Other	35	8	9	5	11	2

Source: Author's own research.

The surveyed companies experience an improvement in competitiveness because of the implemented innovative changes in practically every area of their activity. The greatest impact on the improvement in competitiveness is visible around operational efficiency, in the form of streamlining processes related to the time of task completion and increased production efficiency (Table 9).

Table 9.

Improving competitiveness through innovation

Factor	No improvement	Very small	Small	Mediocre	Big	A very big improvement
Increasing the range of printing products and services;	2	7	19	12	21	9
Entering new markets or increasing share in existing markets;	1	12	12	13	23	9
Reduction of production/labour costs;	3	5	14	16	26	6
Improved product quality/fewer complaints	0	3	16	18	25	8
Improving time-related processes	0	4	12	15	32	7
Increasing work/production efficiency;	0	3	11	16	33	7
Reduced unit price for customers	3	10	18	17	18	4
Increase in the volume of printing orders	1	5	10	23	23	8
Supply chain optimization	1	9	15	18	24	3
Expanding the range of additional services	2	11	11	15	25	6
Development of online ordering platforms	9	7	13	11	26	4

Source: Author's own research.

6. Results

6.1. Verification of the hypotheses

The study aimed to determine whether the innovations implemented in the last three years have a positive impact on the competitiveness of companies in the offset printing industry in Poland, which was reflected in the verification of five detailed hypotheses. The formulated hypotheses were largely confirmed.

Companies that introduced innovations (Table 10) differ from those that did not introduce innovations in the Mann-Whitney U test in terms of: market of operation ($p < .001$, $r = 0.693$, large effect size), number of employees ($p < .001$, $r = 0.556$, large effect size), year of establishment ($p = .002$, $r = 0.307$, large effect size), dominant printing sector ($p < .001$, $r = 0.576$, large effect size), number of machines ($p < .001$, $r = 0.425$, large effect size), and dominant printing format ($p < .001$, $r = 0.540$, large effect size). However, the location of the company was not significant ($p = 0.313$, $r = 0.110$).

Table 10.

Factors of innovation of any type (Mann-Whitney U; $n = 123$)

Factor	p-value	Effect size (r)
Market operation	< .001	0.693
Number of employees	< .001	0.556
Year of establishment	0.002	0.307
Dominant printing sector	< .001	0.576
Number of machines	< .001	0.425
Dominant printing format	< .001	0.540
Company location	0.313	0.110

Source: Author's own research.

H2 is positively verified, as the implementation of innovations is significantly influenced by internal and external conditions of offset printing companies.

Dependence of Innovation Implementation on Internal and External Conditions

All considered structural factors and company environment characteristics, given the reported effect size values, are strong determinants of innovation in the offset printing sector. Further analysis of the directions of influence indicates that, in all cases except for the year of company establishment, there is a negative difference in means. This means that the longer a company has been in business (market experience), the lower the likelihood of innovation. Conversely, the larger the number of employees, the number of offset machines, and the print size, the higher the chance of innovation. Similarly, the broader the market in which a company operates (international, global vs. local, regional), the higher the likelihood of innovation.

Regarding printing types, the likelihood of innovation, ranked from highest to lowest, is as follows:

1. Packaging printing (100%, $n = 32$).
2. Label printing, including IML (100%, $n = 6$).
3. Book printing, including books (83.3%, $n = 24$).
4. Advertising printing (44.6%, $n = 56$).
5. Forms and personalization materials printing (50%, $n = 4$).
6. Newspaper printing (0%, $n = 1$).

None of the structural factors or company environment factors listed so far (Table 11) independently influenced the likelihood of product innovations (no statistically significant differences between groups). The only exception was the dominant printing sector, which independently determines product innovations ($p < 0.001$).

Table 11.

Factors of product innovation (Mann-Whitney U; $n = 123$)

Factor	p-value	Effect size (r)
Market operation	0.135	0.1722
Number of employees	0.819	0.0271
Year of establishment	0.034	0.2123
Dominant printing sector	< .001	0.4281
Number of machines	0.290	0.1285
Dominant printing format	0.297	0.1215
Company location (population size)	0.283	0.1338

Source: Author's own research.

H2 is further positively verified, with evidence that structural and environmental factors strongly determine the likelihood of innovation implementation.

Regarding the factors influencing process innovation, the only statistically significant factor is the length of the company's operation – the younger the company, the higher the likelihood of process innovation ($p = 0.019$).

Table 12.

Factors of process innovation (Mann-Whitney U; $n = 123$)

Factor	p-value	Effect size (r)
Market operation	0.490	0.0782
Number of employees	0.217	0.1406
Year of establishment	0.019	0.2296
Dominant printing sector	0.926	0.0119
Number of machines	0.646	0.0550
Dominant printing format	0.067	0.2086
Company location (population size)	0.128	0.1859

Source: Author's own research.

The implementation of marketing innovations (Table 13) statistically significantly differentiates the sample only in relation to the number of printing machines ($p = 0.027$), while all other factors are not individually significant.

Table 13.

Factors of marketing innovation (Mann-Whitney U; $n = 123$)

Factor	p-value	Effect size (r)
Market operation	0.142	0.1730
Number of employees	0.188	0.1564
Year of establishment	0.530	0.0647
Dominant printing sector	0.930	0.0117
Number of machines	0.027	0.2740
Dominant printing format	0.118	0.1860
Company location (population size)	0.080	0.2229

Source: Author's own research.

None of the considered factors are individually statistically significant in relation to organizational innovations (Table 14).

Table 14.

Factors of organizational innovation (Mann-Whitney U; n = 123)

Factor	p-value	Effect size (r)
Market operation	0.400	0.09424
Number of employees	0.128	0.17129
Year of establishment	0.251	0.11142
Dominant printing sector	0.260	0.13581
Number of machines	0.606	0.06098
Dominant printing format	0.937	0.00942
Company location (population size)	0.131	0.18237

Source: Author's own research.

To examine the impact of both structural and environmental factors on the level of innovation implementation in companies, further analysis was conducted using the Kruskal-Wallis test. This analysis focused on a subgroup of companies that had implemented innovations (n = 85) and considered the degree of novelty (innovation at the company, national, or global level). Within this subgroup, factors such as the number of employees, the company's founding year, market presence, and dominant printing format were not independent determinants of the scale of innovation novelty (no statistical significance). However, the business sector significantly influenced the scale of marketing innovation novelty ($p = 0.024$, $\varepsilon^2 = 0.40$; large effect). Conversely, the number of offset machines was a determinant of the scale of product innovation novelty ($p = 0.003$, $\varepsilon^2 = 0.27$, large effect) and a very strong determinant of process innovation novelty ($p < 0.001$, $\varepsilon^2 = 0.36$).

H3 is positively verified, as the implementation of innovations directly influences the scale of novelty, with factors such as the number of offset machines significantly affecting the novelty of product and process innovations.

Direct Effect of Implemented Innovations on Willingness (Benefits) to Adopt Novel Solutions

Using the Mann-Whitney U test, the benefits derived from innovations were examined within the subgroup of companies that had implemented innovations, using the three-factor model of innovation development (Stanisławski, 2020), which equates to innovation propensity. Statistically significant benefits of product innovations included establishing new relationships with industry entities ($p = 0.010$, $r = 0.381$, medium effect), location (distance from the client) ($p = 0.010$, $r = 0.389$, medium effect), and a reduction in complaints related to printing or post-press finishing ($p = 0.050$, $r = 0.293$, medium effect).

For process innovations, statistically significant benefits were identified in improving employees' qualifications and competencies ($p = 0.023$, $r = 0.31993$, medium effect), location (distance from the client) ($p = 0.035$, $r = 0.29808$, medium effect), and benefits categorized as "other" in the survey ($p = 0.005$, $r = 0.37850$, medium effect).

Marketing innovations were linked to benefits such as establishing new industry relationships ($p = 0.001$, $r = 0.4498$, strong effect), compliance with regulations, norms, or standards related to printing ($p = 0.013$, $r = 0.3410$, medium effect), location (distance from the client) ($p = 0.002$, $r = 0.4345$, strong effect), digitalization of business processes ($p = 0.004$, $r = 0.3954$, medium effect), increased security of data/graphic files ($p = 0.004$, $r = 0.4031$, medium effect), and other benefits ($p = 0.027$, $r = 0.2925$, medium effect).

Statistically significant benefits of organizational innovations included establishing new industry relationships ($p < .001$, $r = 0.51755$, strong effect), compliance with printing-related regulations, norms, or standards ($p < .001$, $r = 0.44408$, strong effect), reducing complaints related to printing or post-press finishing ($p = 0.004$, $r = 0.38612$, medium effect), location (distance from the client) ($p < .001$, $r = 0.47347$, strong effect), supply chain optimization ($p = 0.004$, $r = 0.39102$, medium effect), reduced environmental impact ($p = 0.047$, $r = 0.26939$, medium effect), and other benefits ($p = 0.020$, $r = 0.30122$, medium effect).

H4 is positively verified, as product and marketing innovations are shown to generate the most significant and diverse benefits compared to process and organizational innovations.

Competitiveness Improvement as the Primary Benefit in Domestic and Foreign Markets

Similarly, using the Mann-Whitney U test on data from companies that implemented innovations ($n = 85$), intergroup differences in the development of printing firms' competitiveness were examined. Product innovations were associated with competitive development benefits such as an increase in the range of printed products and services ($p = 0.005$, $r = 0.424$, strong effect), entry into new markets or increased market share ($p = 0.033$, $r = 0.320$, medium effect), supply chain optimization ($p = 0.009$, $r = 0.388$, medium effect), and expansion of additional services ($p = 0.041$, $r = 0.305$, medium effect). Additionally, product innovations had a beneficial impact on the scale of competitiveness improvement for supply chain optimization ($p = 0.029$, $r = 0.302$, medium effect).

Statistically significant benefits for competitiveness improvement from process innovations included streamlining task completion times ($p = 0.003$, $r = 0.40734$, strong effect). However, process innovations did not significantly impact the scale of competitiveness improvement.

Marketing innovations contributed to competitiveness improvement in supply chain optimization ($p = 0.015$, $r = 0.3325$, medium effect), but their impact on the scale of competitiveness improvement was not significant.

Organizational innovations brought significant benefits in terms of supply chain optimization ($p = 0.004$, $r = 0.39102$, medium effect), yet they did not significantly affect the scale of competitiveness improvement.

Variation in Innovation Benefits by Type and Scale, with Product and Marketing Leading

Further exploratory analysis using the Kruskal-Wallis test revealed that none of the listed benefits for innovation development or competitiveness improvement depended on the scale of product innovation novelty. While product innovations were linked to the highest number of statistically significant benefits, the scope of novelty (whether at the company, national, or global level) did not play a determining role.

In contrast, process innovations exhibited fewer benefits overall but showed a strong correlation between the scale of novelty and specific advantages. Benefits dependent on the scale of process innovations included employee qualification and competency improvements ($p = 0.007$), expansion of printed product and service offerings ($p = 0.005$), task completion efficiency ($p = 0.024$), an increase in print order volumes ($p = 0.016$), expansion of additional services ($p = 0.028$), and increased competitiveness due to expanded product offerings ($p = 0.007$) and increased order volume ($p = 0.031$). This suggests that while product innovations bring tangible benefits regardless of novelty scale, process innovations only yield significant advantages when implemented on a national scale.

A similar pattern applies to marketing innovations, where novelty scale was linked to benefits such as improved employee qualifications and competencies ($p = 0.003$), enhanced financial stability ($p = 0.014$), fewer complaints related to printing or post-press finishing ($p = 0.020$), compliance with regulations and standards ($p = 0.031$), increased company stability ($p = 0.044$), faster order fulfilment ($p = 0.014$), expanded product offerings ($p = 0.005$), entry into new markets or increased market share ($p = 0.021$), reduced production costs ($p = 0.010$), and higher productivity ($p = 0.027$). Additionally, the level of marketing innovation novelty appeared to influence firms' perceived adequacy of benefits in relation to their innovation development expectations ($p = 0.036$).

Even more factors were linked to benefits for both innovation development and competitiveness improvement, including higher perceived competitiveness improvement as a benefit of innovation development ($p = 0.016$), expanded product offerings ($p = 0.018$), entry into new markets or increased market share ($p = 0.018$), increased productivity ($p = 0.046$), expanded additional services ($p = 0.004$), and improved competitiveness in the areas of market expansion ($p = 0.003$), task efficiency ($p = 0.032$), productivity ($p = 0.029$), and increased print order volumes ($p = 0.027$).

To assess the markets where competitiveness improvement occurred, the Mann-Whitney U test was conducted ($n = 85$). The results suggest that competitiveness improvements were visible in both domestic and international markets, with stronger effects in international markets. Market conditions influenced the frequency of competitiveness improvement in several areas, including:

Expansion of printed product and service offerings ($p = 0.013$, $\varepsilon^2 = 0.15731$, medium effect), as well as the scale of competitiveness improvement in this area ($p = 0.010$, $\varepsilon^2 = 0.16334$, strong effect).

Entry into new markets or increased market share ($p = 0.050$, $\varepsilon^2 = 0.11357$, medium effect), with the scale of competitiveness improvement in this area being statistically significant ($p = 0.007$, $\varepsilon^2 = 0.17602$, strong effect).

Supply chain optimization ($p = 0.024$, $\varepsilon^2 = 0.13707$, medium effect).

Expansion of additional services ($p = 0.007$, $\varepsilon^2 = 0.17615$, strong effect).

Increased print order volumes ($p = 0.032$, $\varepsilon^2 = 0.12740$, medium effect).

Pairwise comparisons using the DSCF method revealed that significant statistical differences in competitiveness improvement occurred between companies operating in domestic vs. global markets, particularly for expanded product offerings ($p = 0.028$) and increased print order volumes ($p = 0.039$).

H5 is positively verified, as improved competitiveness emerges as the most significant benefit of innovation, observed across both domestic and international markets, with stronger effects internationally.

7. Discussion

Our results are consistent with previous academic publications on innovation in the printing industry as we confirmed that the innovation in this sector encompasses not only technological but also business model (organizational, marketing) innovations (Magadán-Díaz, Rivas-García, 2021; Salwin et al., 2020).

The results confirm Schumpeter's theory assumption that innovation is strongly related to firm-level structural advantage (scale, equipment intensity, market orientation—all enablers of "creative destruction"). However, this theory is partly contradicted by the finding that older companies show lower levels of innovation, even though it assumes that big, well-established firms are the main drivers of innovation.

Scientific interpretations diverged to the time being as to whether innovation capacity stems primarily from company size (Codogini et al., 2013) or whether it is an inherent feature of small and medium-sized enterprises that serve as the engine of the economy (Stanisławski, 2022). Some scholars argued that younger firms are more open to innovation-related risk as part of a resource accumulation strategy rather than for short-term financial return (Coad et al., 2016), and that innovation receptivity may be lower in firms with longer-tenured employees (Verworn, Hipp, 2009). This supports perspectives emphasizing the role of firm age in shaping innovation dynamics (Kalbuana et al., 2022; Xu et al., 2020; Coad et al., 2016; Verworn, Hipp, 2009).

There are no discrepancies with the general interpretation of neo-Schumpeterian models. Their assumptions regarding cumulative learning and organizational capabilities are reflected in the role of internal factors and in the differentiation of innovation outcomes by type. Since the level of novelty correlates with benefits in process and marketing innovations (but not product innovations), this confirms the theoretical assumption that innovation outcomes depend on a firm's absorptive capacity and the integration of technological and organizational procedures (Sancho-Zamora et al., 2022), not solely on the objective novelty of the innovation.

The strategic role of marketing innovation in facilitating digital market access is highlighted in the literature (Magadán-Díaz, Rivas-García, 2021). Innovation benefits are interpreted differently depending on their orientation—those associated with product and marketing innovation are seen as mechanisms of market expansion, while process and organizational innovations relate more closely to internal efficiency. Such differences correspond with broader theoretical models distinguishing between exploration and exploitation, and between externally- versus internally-facing innovation effects (Magadán-Díaz, Rivas-García, 2021).

While the historical development of the printing industry has not been consistent with classical theories of innovation, as the uptake of the printing press had limited macroeconomic effects, contemporary innovations related to digital technologies in this industry have translated primarily into reduced labor costs rather than increased productivity (Chungu, 2024). It is worth noting that the diffusion of innovation theory seems to explain these uncertainties. In light of this theory, it can be argued that despite the ground-breaking nature of the printing press, its adoption may have been limited by the low observability of macroeconomic effects and the slow pace of technology diffusion. In turn, contemporary innovations in printing—though quickly adopted due to their clear cost advantages and ease of testing—are characterized by low compatibility with earlier work models.

Based on our findings, the spectrum of benefits from innovation is much broader in the offset printing industry than in the printing industry as a whole. However, the results are consistent with Rogers's innovation diffusion theory (Rogers, 2003), as innovations are more readily adopted by firms with higher observable performance, suggesting that perceived relative advantage, trialability, and observability also play a significant role in the offset printing industry. It can be added that since young firms were more prone to innovation, this may reflect early adopter profiles, while the differential diffusion of product, process, and marketing innovations—depending on dominant print format, sector, and market scope—corresponds to the assumption of compatibility and complexity as factors in new product adoption (Shaker, George, 2002). Furthermore, the lack of an observed location effect further suggests that diffusion is currently less geographically constrained due to the advances of digital transformation in the sector studied and the favourable models offered by press manufacturers (Salwin et al., 2020).

In light of the three-factor model of innovation development (Stanisławski, 2020), the presented findings confirm that the ability to generate and absorb innovation depends on the company's resources (number of employees, machinery, market reach) as well as its development stage. At the same time, the relatively low correlation between the scale of benefits and the level of novelty of product innovations suggests that the decisive factor in gaining competitive advantage is not the originality of the solution itself, but the ability to commercialize it.

Integrating the presented findings with broader theoretical models reveals that innovation potential in the offset printing sector reflects key tenets of the resource-based approach, which form the basis of sustainable competitive advantage, as innovations enable firms to leverage competitive advantages and—in line with the three-factor model of innovation development—motivate firms to pursue further innovation implementation. The relationship we observed between marketing and product innovations and external performance is consistent with the dynamic capabilities model (Teece et al., 1997). According to these models, firms' ability to detect, utilize, and reconfigure resources in response to a changing environment ultimately determines the scope and impact of innovation outcomes.

Since product and marketing innovations have been shown to deliver broader competitive advantages, while process and organizational innovations tend to promote internal performance, interpretation within the context of exploration and exploitation models is also necessary (March, 1991). The competitive advantage of offset printing companies stemmed from balancing radical, market-oriented innovations with incremental, efficiency-oriented improvements, particularly those promoted by machine suppliers. The variable impact of the scale of novelty, particularly in process and marketing innovations, further reflects the importance of absorptive capacity theory (Zahra, George, 2002).

8. Conclusion

8.1. Empirical Implications

Our study confirms that the vast majority of offset printing companies in Poland implemented at least one innovation in the last three years and observed a measurable impact on competitiveness and innovation development. These innovations varied in terms of type and scale of innovation, with structural and market factors (number of machines, company age, markets served – international orientation) strongly associated with innovation diffusion. Product and marketing innovations generated the widest range of benefits, including market expansion and supply chain optimization, while process and organizational innovations were more closely linked to operational improvements. The scale of innovation did not always correlate with greater benefits, particularly in the case of product innovations.

8.2. Recommendations for Management

Managers in the offset printing industry should recognize that internal potential is a key factor in fostering innovation, but international market presence plays an equally important motivating role. Product and marketing innovations should be emphasized, as they deliver the fastest strategic benefits in terms of competitiveness. Decision-makers should not assume that only breakthrough innovations matter – incremental innovations, especially those targeted at new markets or customer groups, can deliver significant benefits. Sustainable innovation potential requires conscious investment in research and process improvement, especially in the case of process and organizational innovations. Companies should also consider implementing structured mechanisms for tracking and assessing the scale and results of innovation. This is particularly important given the transformation of business models and new forms of collaboration with machinery suppliers. Changing these models involves implementing innovations, such as marketing and organizational ones, but also requires searching for optimal solutions and making choices. Therefore, systematic evaluation of decisions in the context of developing a competitive advantage is essential, as well as the flexible implementation of further changes if the expected results are not achieved.

8.3. Policy applications

The offset printing sector is generic compared to digital printing, but it is still important for the national economy and provides a space for widespread innovation. Our results indicate the significant value of supporting innovation not only through financing high-tech transformation, but also through programs that encourage the development of marketing, service models, and the internationalization of traditional industries, even if the solutions being developed are already used globally. Disruptive innovation is not the only requirement for realizing the benefits of innovative development. Policy should particularly focus on younger and smaller companies with high potential, especially where their development has a real impact on other industries, particularly packaging and labeling. Given that location did not significantly impact innovation levels, regionally neutral digital infrastructure and knowledge dissemination tools—rather than local subsidies—may be more effective in driving the diffusion of innovation throughout the sector.

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PATH TO SUSTAINABILITY: A CASE STUDY OF A POLISH PUBLIC HOSPITAL'S TRANSITION TO GREEN HOSPITAL STATUS

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Purpose: The main aim of the research was to recognize the activities undertaken by Hospital X to achieve Green Hospital status and assess their effects. In addition, the research aimed to identify the strengths, weaknesses, opportunities, and threats associated with Hospital X's transition to Green Hospital status.

Design/methodology/approach: The research goals were achieved through a qualitative research using a case study of Polish Public Hospital X.

Findings: The study indicates that Hospital X's efforts to achieve Green Hospital status involved investments in environmentally friendly infrastructure and renewable energy. Additionally, these efforts encompassed the improvement of key processes and the implementation of a strategy focused on green transformation. As a result of these activities, Hospital X has reduced CO₂ emissions and energy consumption. The strengths of Hospital X in its pursuit of Green Hospital status include the ability to leverage external funding sources, modernization of infrastructure, and a high level of ecological awareness among the management team. However, the Hospital X also faces several weaknesses in its ecological transformation, such as limited financial resources and an aging building constructed with non-energy-efficient technology. The main opportunities for Hospital X include various options for obtaining external funding for environmental initiatives. Meanwhile, the key threats in the external environment involve strict legal regulations. The strengths of Hospital X, together with the opportunities in the external environment, are why the hospital succeeded in achieving Green Hospital status.

Research limitations/implications: The main limitation of the study was that it was conducted only among one hospital.

Practical implications: The study demonstrates how Polish public hospitals can achieve Green Hospital status, offering practical insights that can be replicated by other public hospitals and healthcare facilities in Poland. In particular, the example of Hospital X may encourage other hospitals to secure grants and subsidies for environmental sustainability. Moreover, by highlighting the long-term cost savings associated with energy efficiency and waste reduction, the study can support hospital managers in making informed financial decisions regarding green investments.

Originality/value: The study extends the knowledge on the implementation of the Green Hospital concept in Poland.

Keywords: green hospital; polish healthcare system; public hospitals; climate change.

Category of the paper: Case study.

1. Introduction

Organizations in the health sector offer a diverse range of activities aimed at preventing and treating disease, maintaining human psychological, physical, and social development, prolonging life, and ensuring the healthy development of future generations. Many of these organizations carry out their tasks 24 hours a day, so they constantly consume energy and other resources, produce waste, and emit polluting gases. This state of affairs means that the global health sector is responsible for 4.4 percent of carbon emissions annually (Health Care Without Harm Report, 2022) and places a much greater carbon footprint on the environment than many other sectors, such as shipping or aviation.

In Poland, public hospitals are among the key healthcare entities operating within the healthcare system. In 2023, there were 894 of them in the Polish market and they had 161 200 beds (Główny Urząd Statystyczny, 2024, p. 58). Thus, the contribution of public hospitals to medical waste and carbon emissions is high. Therefore, transforming Polish public hospitals into sustainable institutions is becoming increasingly important. However, despite the potential benefits such as cost savings, improved patient well-being, and compliance with environmental policies, hospitals face numerous barriers to adopting green practices. These challenges include financial limitations, outdated infrastructure, resistance to change, and a lack of clear strategic frameworks (World Health Organization, 2021).

To reduce the negative impact on the environment, some public hospitals in Poland have started to implement the Green Hospitals concept, which is based on the premise of integrating sustainable practices into their infrastructure, operations, and resource management to reduce energy consumption, optimize waste management and promoting green healthcare solutions. Transforming public hospitals into green hospitals is complicated, as public hospitals need to provide comprehensive healthcare services of the highest possible quality to patients while rationally managing the resources at their disposal. Nevertheless, some public hospitals in Poland have been granted Green Hospital status. Hospital X is an example of such hospital. Recognizing the activities undertaken by Hospital X to achieve Green Hospital status and assess their effects has become the main objective of the research presented in this article. In addition, the study aimed to identify the strengths, weaknesses, opportunities, and threats associated with Hospital X's transition to Green Hospital status.

This study provides one of the first in-depth analyses of a Polish public hospital that has systematically implemented the Green Hospital concept and obtained official Green Hospital status. Unlike previous research, which focuses mainly on individual initiatives or sector-wide recommendations, this article reconstructs a two-decade-long transformation process and analyzes it through a structured SWOT framework. This original perspective helps understand the organizational capabilities required for ecological transition in the healthcare sector.

2. Theoretical Background

2.1. The Concept of Green Hospitals

The concept of Green Hospitals refers to the sustainable operation of healthcare facilities aimed at minimizing the negative environmental impact of hospitals while ensuring the provision of high-quality healthcare services (Megariani, Putra, Bayhakki, 2023). Green hospitals can be defined as institutions designed and constructed to utilize natural resources as efficiently and environmentally friendly as possible (Garg, Dewan, 2022). According to Asamoto et al. (2024), Green Hospitals are healthcare facilities that have adopted sustainable design practices as an integral part of delivering high-quality medical services. These hospitals are characterized by carefully considered location, efficient use of water and energy, proper emissions management, and the use of materials that take environmental impact into account (Asamoto et al., 2024).

In order to be classified as a green hospital, a facility must meet specific criteria in areas such as energy efficiency (including the use of alternative energy sources), environmentally conscious building design, transportation, food services, and waste and water management (Alkaabi, Aljaradin, 2022; Rupiwardani et al., 2022). To fulfill these criteria, hospitals must undertake a range of initiatives encompassing both core medical activities and supporting processes. Examples of such initiatives are presented in Table 1.

Table 1.
Examples of Actions Supporting the Implementation of the Green Hospital Concept

FIELD	ACTIONS
Energy Management	• Use of energy-efficient devices and technologies. • Utilization of renewable energy sources.
Eco-friendly Building Design	• Selection of building and finishing materials with low levels of harmful substances and sourced from recycling. • Location in well-connected areas with public transportation. • Development of existing green spaces on hospital grounds. • Consideration of sustainable development principles when designing and constructing new hospital buildings. • Monitoring air quality both inside and outside the buildings.

Cont. table 1.

Water Management	• Use of water-saving sanitary devices and water recycling systems.
Waste Management	• Segregation of medical and municipal waste. • Sorting medical waste by material type and risk level. • Ensuring safe disposal of medical waste in accordance with applicable regulations. • Reducing treatment duration. • Implementing IT systems for medication management. • Responsible management of chemicals and hazardous materials, minimizing usage, and ensuring safe storage and disposal.

Source: Own study based on: Borges de Oliveira & de Oliveira (2022), Collada Sánchez et al. (2023), Harhay et al. (2009), Loumer (2015), Megariani, Putra, Bayhakki (2023), Mkalaf et al. (2023), Nielsen, Hansen (2007), Sant'Anna, Gaviña, Lima (2022), Suwasono, Suman, Yanuwadi (2013), Tsiumpri, Tsakni, Goula (2020).

The actions that a hospital should undertake in order to become a green hospital encompass not only technical and organizational aspects, but also the education of staff and patients. Green hospitals should also implement training programs for staff focused on sustainable development and environmental protection, raise ecological awareness among patients and visitors, and promote responsible behavior (Mkalaf et al., 2023). Furthermore, they should seek and implement innovative environmentally friendly solutions (Megariani, Putra, Bayhakki, 2023). Megariani, Putra, and Bayhakki (2023) also emphasize the importance of developing and implementing an environmental policy within the hospital, as well as monitoring and evaluating the effectiveness of implemented measures to support continuous improvement.

Based on research findings related to the implementation of the green hospital concept in Indonesia, it can be observed that green hospitals offer not only environmental but also health-related, social, and economic benefits (Rupwardani et al., 2022; Rahma, Winny, Maria, 2022). Green hospitals can enhance the treatment process and contribute to reducing emotional stress, depression, and anxiety among patients (Dadvant et al., 2012). Moreover, green hospitals may positively affect employee satisfaction, well-being, and comfort (Kim et al., 2015). They can also achieve benefits in terms of reduced operational costs through efficient resource management, decreased energy and water consumption, and waste reduction (Borges de Oliveira, de Oliveira, 2022).

2.2. Development of the Green Hospital concept in Poland

Polish public hospitals, similar to those in other countries, are characterized by high levels of energy and water consumption, as well as the generation of significant amounts of medical waste (Tomiak et al., 2024). Therefore, improvements are needed in both energy and waste management, particularly in the area of hazardous and medical waste. According to the Supreme Audit Office of Poland, numerous irregularities exist in Polish hospitals regarding the storage, segregation, and disposal of hospital waste, indicating the need for more effective management procedures in this domain (Naczelną Izba Kontroli, 2022).

The concept of Green Hospitals represents a forward-looking solution aimed at reducing the negative environmental impact of public hospitals in Poland (Lurka, 2025). The implementation of this concept has been undertaken by the Polish Hospital Federation, which, under the "Green Hospitals – Polish Hospital Federation" project, developed a strategy outlining priorities for the sustainable development of public hospitals. This document focuses on aspects such as achieving carbon neutrality, waste management, improving energy efficiency, and enhancing working conditions for staff and comfort for patients. The implementation of these principles takes place within the broader context of social determinants of health and the increasing emphasis on ecological solutions in the healthcare sector (Polska Federacja Szpitali, n.d.).

Among the activities undertaken in Polish hospitals as part of the Green Hospital concept is the initiative known as "eco-dialysis". This involves promoting environmentally friendly systems for the delivery of dialysis concentrates. The "eco-dialysis" initiative may contribute to reduced water and energy consumption as well as a decrease in waste generated by dialysis centers (Zawierucha et al., 2023). Another initiative involves the search for ecological methods of delivering dialysis fluids, aimed at reducing both the flow rate and consumption of dialysis fluid, as well as the production of wastewater. Each hemodialysis session consumes more than 500 liters of water, making this an increasingly important issue in light of the depletion of natural resources (Wieliczko et al., 2020). Other examples of activities undertaken within the green hospital framework include recycling efforts, emission reduction initiatives, material conservation, and waste minimization (Swalek, Steinerowska-Streb, 2023).

It is worth noting that pro-environmental actions in Polish hospitals have been implemented since 2004, although they were not initially defined as part of the Green Hospital concept. One such example is the thermal modernization of hospital buildings, made possible through access to European Union funds (Przesmycka et al., 2023). Another example is the gradual implementation of electronic medical records in Polish hospitals after 2011 (Swalek, 2024).

A key milestone in the development of the green hospital concept in Poland was the establishment of the Green Coalition for Health in 2024. This cooperation platform is directed at healthcare institution managers, local government representatives, and policymakers. Its aim is to implement innovative solutions that minimize the environmental impact of hospitals, facilitate knowledge exchange, and promote best practices in sustainable healthcare management (Zielona Koalicja dla Zdrowia, n.d.).

Although recent studies increasingly examine various aspects of green hospitals, they tend to focus on selected areas such as energy efficiency (Borges de Oliveira, de Oliveira, 2022), waste management (Suwasono et al., 2013), or sustainable building design (Asamoto et al., 2024), without analyzing the long-term organizational transformation required to achieve full Green Hospital status. Research conducted in Indonesia, Japan, or Western Europe (Rupwardani et al., 2022; Tsioumpri et al., 2020) confirms the growing relevance of sustainability in healthcare, yet similar analyses are largely absent in Central and Eastern

Europe, particularly in Poland. According to what we were able to find, there are no studies referring and reporting on a comprehensive, multi-year transition of a Polish public hospital toward obtaining Green Hospital status. This indicates a clear research gap that the present article addresses.

3. Methodology

The main aim of the research was to recognize the activities undertaken by Hospital X¹ to achieve Green Hospital status and assess their effects. In addition, it aimed to identify the strengths, weaknesses, opportunities, and threats associated with Hospital X's transition to Green Hospital status. Achieving these objectives required answering the following research questions:

RQ1: What activities were performed by Hospital X to achieve Green Hospital status?

RQ2: Which activities Hospital X undertook to achieve Green Hospital status were the most challenging?

RQ3: What are Hospital X's strengths in pursuing green solutions?

RQ4: What are Hospital X's weaknesses in pursuing green solutions?

RQ5: What are the opportunities in the Hospital X environment that favor the introduction of green solutions?

RQ6: What threats may constrain Hospital X in pursuing green solutions?

RQ7: What results does Hospital X achieve by introducing green solutions?

The established objectives were achieved using a case study. That method was chosen because it is one of the key methods that enable a detailed understanding of the phenomena under study in their natural context (Yin, 2018). Using a case study as a research method is particularly effective when the research field is emerging, as case studies capture contextual factors that may not be noticed in qualitative research. In particular, case studies help identify best practices, challenges, and solutions that may not be apparent in theoretical models.

The case study included interviews, observations, and document analysis. The documentation review included internal reports made available by Hospital X, information posted on Hospital X's website, and information concerning Hospital X, which can be found in the Public Information Bulletin. In addition, the review covered press materials and reports published by the founding authority and the city authorities where Hospital X is located.

The gathered data concerning Hospital X was analyzed in detail in the context of the set objectives. In particular, these data were used to conduct a SWOT analysis of Hospital X. That kind of analysis is widely used for assessing different organizations' Strengths,

¹ The authors do not have permission to use the full name of the hospital.

Weaknesses, Opportunities, and Threats. It highlights areas requiring improvement and helps anticipate challenges before they escalate. Likewise, it allows organizations to develop unique capabilities that provide a competitive edge and enhance resilience and sustainability.

4. Results

4.1. Case study

Public Hospital X was established in the 1950s on former municipal forest land by the Self-Government of the Greater Poland Voivodeship. It is a non-commercial medical entity operating as an independent public healthcare institution. As a healthcare provider, Public Hospital X has been classified—according to the list of service providers qualified for the various levels of the basic hospital healthcare security system in the Greater Poland Voivodeship, effective from January 1, 2023, to June 30, 2027 (PSZ, 2022)—as an oncology or pulmonology hospital. The hospital's primary area of activity is the provision of medical services, both inpatient and outpatient, for adult patients suffering from pulmonary disorders, lung diseases, and tuberculosis. Public Hospital X comprises four wards, three diagnostic units, an outpatient clinic, and an emergency admission unit. Notably, in 2022, Public Hospital X became the first healthcare facility in Poland to join The Global Green and Healthy Hospitals—the world's largest network promoting sustainable healthcare.

Data collected for the purposes of this study indicate that since 2004, Public Hospital X has been consistently implementing a pro-environmental strategy, continuously adapting its infrastructure and operations to the principles of the green hospital concept. Undertaken initiatives include building modernization, investments in renewable energy sources, optimization of resource consumption, and collaboration with national and international organizations in the area of sustainable development. One of the first actions taken under the hospital's pro-environmental strategy was the modernization of its boiler plant in 2004. The coal-based system was replaced with a more environmentally friendly gas-oil system, resulting in a significant reduction in carbon dioxide and other pollutant emissions. In 2017, the hospital commissioned a modern wastewater treatment plant, capable of effectively eliminating harmful phosphorus and nitrogen compounds, in compliance with EU standards. Another major initiative aimed at reducing heat loss and energy consumption was the thermal modernization of hospital buildings in 2018. This project involved the insulation of walls, replacement of windows, and upgrading of heating systems. In 2021, the hospital expanded its sustainable development efforts by acquiring a bronchoscope with endobronchial ultrasound (EBUS), allowing certain diagnostic procedures to be performed on-site. This reduced the need for patient transport to external facilities, thereby lowering the hospital's carbon footprint.

In the same year, Public Hospital X also established cooperation with the World Health Organization (WHO) to support the implementation of sustainable development strategies.

In 2022, Public Hospital X carried out a series of key investments aimed at increasing energy efficiency and optimizing the use of natural resources:

- Installation of photovoltaic panels covering an area of 968 m² on the hospital's roof and grounds, with a total capacity of 199.8 kWp, which significantly reduced the hospital's consumption of electricity from conventional sources.
- Expansion of the hospital with a new wing constructed using modern modular technology and energy-efficient building materials. The project included the installation of a recuperation system and a Building Management System (BMS), which enables real-time monitoring and optimization of energy use.
- Installation of a rainwater harvesting system consisting of six underground tanks with a total capacity of 45 m³, enabling the collection of up to 900 m³ of water annually, which is used for irrigating green areas.
- Acquisition of a composting device for biodegradable waste, contributing to a reduction in the volume of waste sent to landfills.

In 2023, the hospital continued the modernization of its infrastructure. The boiler plant was upgraded from a coal-based to a gas-oil system, which led to a 30% to 45% reduction in carbon dioxide emissions and other harmful gases and particulates compared to hard coal combustion. In addition, the hospital utilizes heat pumps as a secondary energy source. Public Hospital X also undertook actions in support of international cooperation in the area of green hospitals. A partnership agreement was signed with a hospital on the island of Syros (Greece), aimed at promoting environmentally responsible practices in the healthcare sector. Moreover, the hospital is engaged in long-term initiatives such as education, ecotherapy, and the promotion of the green hospital concept through the organization of conferences and awareness-raising activities.

The Head of the Administrative and Operational Department at Public Hospital X, who was interviewed for the purpose of this study, emphasized that the greatest challenge in pursuing green hospital status is financial constraints. His statement was as follows: *The biggest problem is simply the financial condition of the healthcare sector in Poland. It's terrifying to even think about trying to implement an environmentally friendly initiative, because the governing bodies immediately ask: How? Where will the money come from? It costs so much.* He also pointed out the lack of incentives for staff to engage in environmentally friendly actions: *We wanted to encourage them, but since there were no financial rewards attached to it (...) it just didn't work out; Money still remains the strongest motivator. If there were more financial resources—if the director had the freedom, for instance, to appropriately reward those who come up with initiatives—things might look different.* The department head also stressed that awareness, a sense of agency, and intrinsic motivation among all hospital staff are crucial for successfully implementing green solutions: *That's when everything starts to work and make sense—*

when those involved in the process are doing it because they are aware and genuinely want to. Despite the many pro-environmental initiatives already implemented at Hospital X, the Head of the Department noted that in the near future, the hospital plans to continue thermal modernization efforts in the remaining buildings, as well as actions related to the heating system.

4.2. SWOT Analysis of Public Hospital X

The analysis of the data collected on Public Hospital X indicates that its key strengths in implementing the Green Hospital concept lie primarily in its systematic investments in environmentally friendly infrastructure as well as in modern diagnostic equipment. As early as 2004, Hospital X underwent modernization and began investing in renewable energy sources. This was followed by the implementation of solutions aimed at reducing energy and water consumption and minimizing harmful emissions. Additionally, energy-efficient diagnostic equipment was acquired.

Another strength of Hospital X is its location. The hospital is situated in the middle of a pine forest, on a plot exceeding 23 hectares in size. This natural environment has a direct influence on the functioning of the hospital. Nature contact is actively integrated into patient therapy—for example, through a green health path and a relaxation area featuring aromatherapy. The hospital's location also contributes to a high level of environmental awareness and a strong sense of responsibility for environmental stewardship among the hospital's leadership and management. Another significant strength of Hospital X is its qualified medical staff, committed to maintaining high-quality services and continuously improving their professional competencies. The hospital also holds ISO 9001:2015 (Quality Management System) and ISO 14001:2015 (Environmental Management System) certifications, which further confirm its commitment to quality and sustainability. Equally important is the hospital's active cooperation with various partners and organizations specializing in green technologies and sustainable development. This collaboration brings valuable know-how and access to additional resources. In the context of sustainable development, it is also beneficial that since 2022, Hospital X has been a member of the international organization Global Green and Healthy Hospitals, as well as a partner of the Green Coalition for Health and UN Global Network Poland, operating under the auspices of the United Nations and in cooperation with Philips Health Care.

A key weakness of Public Hospital X in obtaining and maintaining Green Hospital status is the technology used during its original construction, as many of the solutions implemented at that time no longer meet current environmental standards. The aging infrastructure in some cases makes modernization impossible, or it becomes highly costly and time-consuming.

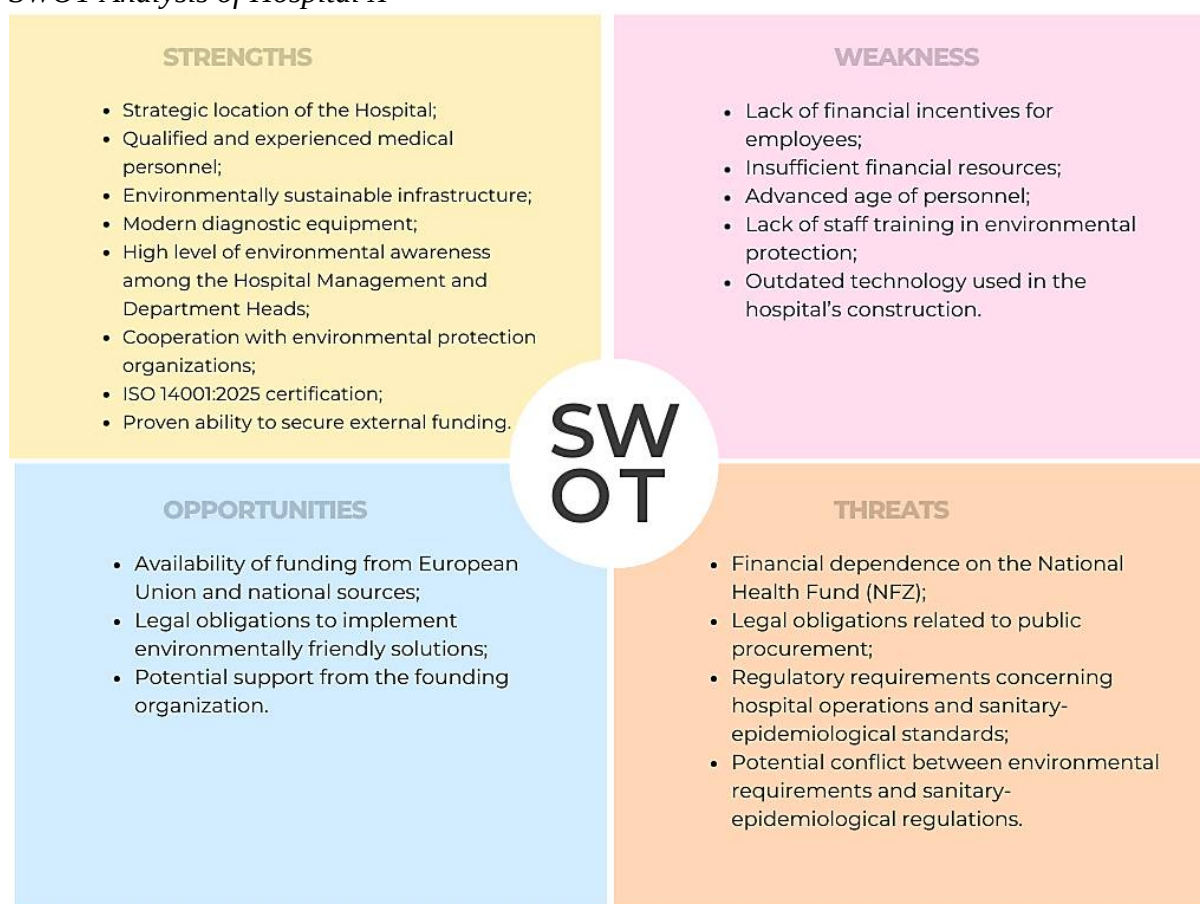
Another significant weakness is the hospital's limited financial resources, as investments in green technologies and sustainable solutions require substantial capital. Securing adequate funding for such investments poses a challenge for Hospital X. Financial constraints also result in low salaries for both medical and administrative staff, which may lead to employee demotivation and staffing issues. This situation discourages staff engagement in additional responsibilities. Moreover, due to budget limitations, the hospital is unable to provide training related to sustainable development practices. Data analysis also reveals a structural weakness: the aging medical staff. Each year, the risk of staff shortages among physicians increases as more approach retirement age, and there is an insufficient influx of younger doctors. Potential personnel shortages may further limit the hospital's capacity to engage in environmental initiatives. Although Hospital X holds an ISO 14001:2015 certification (Environmental Management System), the time and costs associated with maintaining the certification and potential recertifications may also constitute a weakness.

A key opportunity for Hospital X in its efforts to maintain Green Hospital status is the financial support available for environmental projects from the Regional Fund for Environmental Protection and Water Management. Hospital X has previously benefited from this fund by securing financing for building modernization projects. Another opportunity lies in the potential to obtain additional funding and resources for ecological initiatives from its founding authority—the Self-Government of the Greater Poland Voivodeship.

Among the main threats to maintaining Green Hospital status is the hospital's financial dependency on the National Health Fund (NFZ). Financial instability within the NFZ and changes in healthcare service funding limit the hospital's investment capacity and hinder long-term planning. Further threats include the hospital's obligation to comply with strict sanitary and epidemiological standards. The implementation of green solutions must fully respect these regulations in order not to pose additional risks to patients. As such, potential conflicts may arise between medical guidelines and ecological practices. Additionally, the hospital is subject to the Public Procurement Law, which can limit its flexibility in selecting suppliers and thus impede the implementation of sustainable solutions. Finally, changes in legislation that impose new ecological obligations on the hospital are of significant importance—especially in the context of its Green Hospital status. These changes directly influence the hospital's responsibilities and actions, requiring continuous adaptation of its procedures to current environmental requirements.

The results of the SWOT analysis conducted for Public Hospital X in the context of implementing Green Hospital initiatives are presented schematically in Table 2.

Table 2.
SWOT Analysis of Hospital X



Source: Own study based on collected data.

5. Discussion

Based on the conducted analysis, it can be concluded that Hospital X undertakes systematic and comprehensive efforts toward sustainable development, which have enabled it to obtain Green Hospital status. These efforts include both investments in infrastructure and changes in operational processes. Implemented initiatives—such as thermal modernization of buildings, installation of renewable energy sources, advanced resource management, and innovative diagnostic and treatment solutions—have significantly contributed to reducing CO₂ emissions and improving energy efficiency. It is also worth emphasizing that Hospital X is engaged in international cooperation and environmental education, which further strengthens its position within the sustainable healthcare sector.

However, the implementation of actions aimed at achieving and maintaining Green Hospital status does not come without challenges. Hospital X faces a number of obstacles in this area, among which financial constraints play a crucial role. The lack of sufficient funds for ecological

investments and the absence of effective incentive mechanisms for staff hinder the initiation of new activities within the Green Hospital framework.

The study indicates that Hospital X possesses numerous strengths that support its Green Hospital status, including its ISO 14001:2015 certification, which confirms the implementation of an environmental management system. Another notable strength is the awareness and support of the hospital's management team, as well as its active participation in international initiatives such as membership in Global Green and Healthy Hospitals and partnerships with the Green Coalition for Health and UN Global Network Poland. Nevertheless, Hospital X also demonstrates certain weaknesses in relation to the implementation of Green Hospital activities. These include limited financial resources, an overburdened and aging workforce, and insufficient resources that may hinder the hospital's ability to renew its ISO 14001:2015 certification due to the time-consuming and costly nature of the recertification process. Among the key opportunities that could help mitigate the hospital's weaknesses is the availability of funding from the Regional Fund for Environmental Protection and Water Management, which Hospital X has already successfully accessed to support infrastructure modernization projects. Another opportunity lies in securing additional funding and resources for ecological projects from the hospital's founding authority—the Self-Government of the Greater Poland Voivodeship. In contrast, the main threats to maintaining Green Hospital status include the hospital's financial dependence on the National Health Fund (NFZ). Ongoing financial difficulties within the NFZ and changes in healthcare financing significantly limit the hospital's investment capacity and complicate long-term planning. Additionally, strict sanitary and epidemiological regulations, along with the requirements of public procurement law, may constrain the hospital's flexibility in selecting suppliers and technologies that meet ecological standards. Legal changes that impose new environmental obligations are of particular importance for Hospital X, especially given its Green Hospital designation. These changes directly impact the hospital's operations and require it to continuously adapt its procedures to comply with updated environmental standards. One potentially helpful resource in navigating these legal complexities is the "Guide to Current Legal Regulations in the Area of Green Public Procurement", published in 2022 by the Public Procurement Office. This publication is intended to direct public investments toward the use of more environmentally friendly products, raw materials, technologies, and innovations (Public Procurement Office, 2022). It can be expected that other hospitals pursuing transformation toward Green Hospital status may face similar challenges. Therefore, the experience of Hospital X—considered a model example of the first hospital in Poland operating in line with the Green Hospital concept—offers valuable insights. Based on the conducted analysis, it can be also concluded that transformation of Hospital X towards the 'Green Hospitals' status depended on its gradual accumulation of dynamic capabilities, such as the capacity to absorb external financing, learning capabilities resulting from international collaboration, and integrative capabilities enabling the coordination of infrastructural and operational innovations.

These findings suggest that long-term ecological transformation of public hospitals may result not only from their financial condition and financial support possibilities but also from their organizational capabilities.

The findings of this case study are confirmed by other research. As suggested by Megariani, Putra, and Bayhakki (2023), access to external funding and state budget support, as well as growing environmental awareness among staff and leadership, constitute key opportunities for hospitals. Moreover, collaboration with environmental organizations is perceived as a valuable enabler for implementing green initiatives. On the other hand, hospitals' financial limitations, insufficient public awareness of environmental issues, potential conflicts between medical and environmental priorities, and resistance to change among staff are identified as key threats and weaknesses (Bayhakki, 2023).

Conclusion

Public hospitals, like other modern organizations, must align their operations with environmental protection regulations and policies. The urgency and necessity of taking action in this area stem from both academic research and real economic challenges, including the current energy crisis. Although public hospitals are undertaking initiatives to minimize their negative environmental impact, the level of environmental integration across individual organizational units remains varied.

The main limitation of this study lies in the fact that it focused on a single public hospital in Poland, which prevents the generalization of findings to all facilities of this type in the country. Other public hospitals may differ significantly in terms of organizational structure, available resources, and commitment to environmental issues. Future research should involve a broader sample of respondents and include a larger number of public hospitals in Poland, to enable more generalizable conclusions. Such studies could also incorporate the perspective of hospital employees by using qualitative methods such as individual interviews.

The results of this study offer preliminary conceptual implications for innovation and capability theory. The case of Hospital X demonstrates that the transformation of public hospitals toward green hospitals depends on the gradual accumulation of dynamic capabilities—such as the capacity to absorb external financing, learning capabilities resulting from international collaboration, and integrative capabilities enabling the coordination of infrastructural and operational innovations. These results extend existing theoretical perspectives by suggesting that long-term ecological transformation in public healthcare organizations results not from isolated technological changes but from an evolving configuration of organizational capabilities shaped by regulatory and financial conditions. The findings of this study have several important practical implications. The research

demonstrates how Polish public hospitals can achieve Green Hospital status, offering practical insights that can be replicated by other public healthcare institutions across Poland. In particular, the case of Hospital X may serve as an example for other hospitals, encouraging them to seek grants and subsidies for environmentally sustainable development. Additionally, by highlighting the long-term cost savings associated with energy efficiency and waste reduction, this study may support hospital administrators in making informed financial decisions regarding green investments.

The results of this study extend existing knowledge concerning ecological innovation by revealing that ecological transformation of public hospitals stems from an evolving configuration of organizational capabilities shaped by regulatory and financial conditions. In light of this conclusion, the present study opens up new research avenues focusing on a dynamic and contextual approach to ecological innovation in public healthcare organizations. Key directions for future research cover further conceptualization and measurement of organizational capabilities in public hospitals in the context of implementation of ecological innovations. Future research may also empirically test the model presenting the complex relationship between regulatory conditions (e.g., EU directives, national health policies), financial constraints (e.g., public funding, reimbursement models), and the introduction of ecological innovations. It would also be useful to capture the long-term and evolutionary nature of the green transformation of public hospitals and conduct longitudinal studies in this field. In this way, future research can significantly contribute to the development of innovation theory within the context of ecological innovation in the public sector.

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DETERMINANTS OF THE QUALITY OF EDUCATION FROM THE STUDENTS' PERSPECTIVE

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Purpose: The aim of the survey was to assess the perceptions of students in the Faculty of Management and Quality Science at Gdynia Maritime University (FMQS GMU) on factors affecting the quality of education.

Design/methodology/approach: The study was conducted by means of a diagnostic survey with the use of the author's own questionnaire.

Findings: It was found that, in the opinion of the students of FMQS GMU the quality of education is determined to the greatest extent by factors related to academic staff and the organisation of classes, and to the least extent by factors related to students themselves. When analysing the results at the level of individual factors, however, it was found that the quality of education is most influenced by the content-related competences of the academic teachers, the equipment of the laboratories, the teaching skills of the teachers (conveying knowledge and explaining issues in a simple and understandable way) and the provision of teaching materials, e.g. lecture presentations or additional studies, by the teachers to the students.

Research limitations/implications: The survey was conducted among students of only one university. The results obtained cannot therefore be generalised to the entire student population in Poland.

Practical implications: The results of the study may serve as an inspiration for the university to define and implement activities aimed at improving the quality of teaching services provided, and as a result, increasing student satisfaction with the quality of education.

Originality/value: To identify the factors which, in the opinion of students, determine the quality of education to the greatest extent, and thus should be prioritised by universities when taking measures to improve the services provided.

Keywords: quality of education, university, students.

Category of the paper: Research paper.

1. Introduction

A key factor determining the competitiveness of modern universities, and thus the competitiveness of national higher education systems, is the quality of education. Under the provisions of the Bologna Process, all universities operating within the European Higher Education Area are obliged to implement activities aimed at ensuring high-quality education (Kraśniewski, 2009; Kujawa, 2021). Poland, as a signatory to the Bologna Declaration, has accepted the obligation to respect and implement the provisions contained therein, hence the provision of top quality education has been recognised as one of the pillars of the mission of the Polish system of higher education and science (Ustawa..., 2018).

The quality of education can be defined as the degree of meeting the requirements formulated by various groups of university stakeholders (students, teaching staff, business environment, accrediting institutions, state authorities), which relate to the education process and its effects, taking into account internal and external conditions (Roszczynialski, 2020). Due to the fact that stakeholders perceive different characteristics affecting the quality of education and have different priorities in this regard, it is difficult to indicate a single, universally acceptable definition of the quality of education (Biolik, 2009; Popek, Świda, 2011; Jabłońska, Wróbel, 2009).

The university's most important stakeholder are the students, for whom the quality of education is becoming increasingly important and who are looking for ever higher standards in this respect (Jabłońska, Wróbel, 2009). Achieving and maintaining student satisfaction and loyalty is currently one of the fundamental problems of university management staff, hence the activities related to the design and improvement of the university's offer should be implemented in a systematic manner (Duchnowska, 2019). Most authors of definitions of educational quality presented in the literature emphasise that the concept focuses on the student, as the most important stakeholder of the university, and the fulfilment of their needs and expectations. According to Gos (2015), the quality of education is such a level of teaching for students that guarantees the acquisition of knowledge, skills and competences in accordance with continuously improved educational programmes that are accepted by the university environment. According to Machowska-Okrój (2023) it is the sum of positive features of the teaching process, relevant from the students' point of view, which can be objectively measured. Malinowska and her team (2014) defined educational quality as a set of characteristics of the educational service provided by a university that satisfy the current and future requirements of students in terms of skill formation and knowledge transfer. Przystupa (2017), in turn, states that the quality of education is determined by students' satisfaction with the knowledge and skills they have acquired and by the usefulness of the competences acquired during their studies to meet the identified or foreseeable needs of the job market.

The link between educational quality and students' needs and expectations is also highlighted in the document 'Standards and Guidelines for Quality Assurance in the European Higher Education Area', approved by the Ministerial Conference in May 2015. According to these guidelines, the quality of education is linked to the objectives of education, and one of these objectives may be to prepare students for active citizenship and future professional work (by increasing their competitiveness in the job market, supporting their personal development or providing advanced knowledge) (Wytyczne dla EOSW; Machowska-Okrój, 2023). These guidelines impose on universities the obligation to implement and develop internal systems for ensuring the quality of education, the integral element of which should be the systematic assessment of the effects of the education process and the analysis of students' satisfaction with the quality of didactic classes (Gotlib, 2011).

By providing and improving the quality of education, universities should systematically monitor the needs and expectations of students to take into account their point of view. Most often, universities collect and analyse students' opinions on the quality of classes and the work of academic staff, as such activities are a formal and legal requirement imposed on Polish universities by the Act of 20 July 2018. Law on Higher Education and Science (Ustawa..., 2018). In fulfilling this obligation, universities conduct evaluation using questionnaires, which are the most popular and most widely used method of surveying students' opinions about the quality of courses (Hall, 2022; Horstein, 2017; Serin, 2019; Wach-Kąkolewicz, 2015). However, this approach is insufficient because, as Akareem i Hossain (2016) point out, the quality of education from the students' perspective should be assessed not only through the evaluation of teaching activities, but also, more broadly, through the evaluation of the learning environment throughout the study period. This is necessary to determine which factors most strongly determine the students' perception of the quality of education, to identify the needs for improving the didactic processes implemented by the university and to determine priorities in this regard (Wójcik, 2017). Identifying the attributes of an educational service that are important to students and prioritising them in terms of importance forms the basis of design and improvement activities for the university's offer, as achieving student satisfaction by meeting their needs and expectations is the basis for building relationships with them and loyalty to the university (Duchnowska, 2019). Being able to achieve student satisfaction is also a source of benefit for both the students themselves, the academic staff and the universities, operating in a dynamically changing environment (Bielińska-Dusza et al., 2023). The survey of student opinions on the quality of education also highlights the role of students as partners of universities in the development of the services they provide (Roszczynialski, 2020). In doing so, universities should bear in mind that a survey of students' perceptions of the quality of education should be carried out systematically, since the factors on which student satisfaction depends are not only very different, but also their impact on student satisfaction may change over time (Biesok, Wyród-Wróbel, 2015).

Different views on the factors shaping the quality of education are presented in the literature on the subject. Roszczynialski (2020) notes that educational quality can be considered externally, in terms of compliance with higher education legislation, as well as internally, in terms of the fulfilment of students' needs and expectations relating to the educational service. According to Krajewska (2016), the determinants of the quality of education can be considered in terms of object (from the perspective of the university) and subject (from the perspective of participants in the education process). In terms of the object, the quality of education is determined, among other things, by the educational programme, the learning environment, the resources of the HEI, the evaluation of results (achievements), the mission, policies and objectives of the HEI, the management of the HEI, the staff of the HEI, the structure of the HEI, the organisation and course of the educational process. On the other hand, in terms of subjects, the quality of education is determined by factors related to teachers (e.g. the educational methods used, competences, attitudes towards students, commitment to the educational programme, requirements for students) and students (their motivation, commitment to classes and learning).

Among the determinants of educational quality, Gos (2015) mentions the teaching staff, the material base, the educational programmes and the procedures for improving the educational process. In turn, Jabłońska i Wróbel (2009) point out that the quality of teaching processes is shaped by factors such as the study programme, the organisation of classes, teaching methods, student assessment methods, teaching staff, recruitment conditions, the learning environment and teaching aids. Numerous factors determining the quality of education are also mentioned by Popek i Świda (2011). They include:

- methods of program implementation (reduction in the proportion of lectures and predominance of student-activated activities),
- programme delivery standards (including qualifications of academic staff),
- group sizes adapted to the form of the classes,
- daily teaching load,
- consultations for students,
- teaching aids made available to students,
- student assessment principles,
- premises for carrying out activities,
- equipment to support the learning process,
- access to the library,
- information infrastructure and an integrated learning management system,
- cultural, sporting and recreational facilities,
- social and health care facilities,
- administrative and support services.

The determinants of educational quality and their importance in terms of their impact on student satisfaction have been the subject of numerous studies. For example, Wójcik (2017) conducted a study to assess the extent to which selected factors related to the organisation of the educational process affect the quality of university education as assessed by students of natural sciences. Hall (2011) assessed the validity of didactic and non-didactic criteria determining student satisfaction at one technical university in Poland. Research to identify the key determinants of student satisfaction was also carried out by Szeliga-Duchnowska and Szewczyk (2019), who, using the Kano method, distinguished between attributes of an educational service that are obligatory, one-dimensional, attractive and indifferent from the students' point of view. In turn, Kocot and Kwasek (2024) made an attempt to assess students' expectations towards study programmes, the importance of individual elements of the programme and their impact on student satisfaction. In another study, Akareem and Hossein (2016) assessed how students' sociodemographic characteristics, as well as their status and background, affect their perceptions of the quality of education. Biesok's and Wyród-Wróbel's study (2015), on the other hand, aimed to assess the impact of factors related to lecturers' attitude and approach to classes on student satisfaction.

The aim of the survey was to assess the perceptions of students in the Faculty of Management and Quality Science at Gdynia Maritime University (FMQS GMU) on factors affecting the quality of education. Based on the objective formulated in this way, it was hypothesized that individual factors determine the quality of education and student satisfaction with the services provided by universities to varying degrees. The research problem posed in the study was to identify which factors have the greatest impact on students' perceptions of educational quality and thus should be prioritised by universities when implementing improvement measures.

The novelty of the research stems from an identified research gap - research aimed at finding out the opinions of students of FMQS GMU on the factors determining the quality of education had not been previously conducted at the Faculty. Therefore, no factors have been identified thus far that, in the opinion of the students of the Faculty, have the greatest impact on their satisfaction with teaching quality. The originality of the survey results obtained lies in the identification of factors that should be prioritised by the Faculty when taking measures to improve the quality of the education service provided.

The article was prepared on the basis of an analysis of the literature devoted to the issue of the quality of education services provided by universities, with particular emphasis on the factors determining this quality, as well as on the basis of the results of a survey conducted among students of FMQS GMU.

2. Methods

The study was conducted by means of a diagnostic survey with the use of the author's own questionnaire. The questionnaire contained three questions. The first was designed to assess students' perceptions of the extent to which factors related to academics, study programme, students, organization of the classes and university infrastructure affect the quality of education. A five-point ordinal scale was used to assess the influence of each factor, where 1 meant definitely not influential and 5 meant definitely influential. The remaining two questions, which were single-choice in nature, sought students' evaluations of the effectiveness of different forms of course delivery. The survey questionnaire was made available to respondents online, as well as on paper during teaching sessions. The selection of the sample was intentional and non-random. The research was carried out between January and November 2024.

264 students from the Faculty of Management and Quality Science at Gdynia Maritime University took part in the survey, representing different fields of study (Management, Quality Science, Quality Engineering), degree (first-cycle, second-cycle) and form of study (full-time, part-time). The structure of the respondents is shown in Table 1.

Table 1
Structure of respondents by fields, degree and form of study

Differentiating factor		n	%
Fields of study	Management	138	54
	Quality Science	45	18
	Quality Engineering	73	29
Degree of study	first-cycle	202	79
	second-cycle	54	21
Form of study	full-time	189	74
	part-time	67	26

Source: own elaboration.

The results obtained were analysed using descriptive statistics methods. Due to the lack of proportion in the size of specific groups of respondents and the related limited possibilities of using statistical tests, the results were not analyzed using statistical inference methods to determine the diversity of students' responses depending on the differentiating factor.

3. Results and discussion

The factors influencing the quality of education and student satisfaction with the services provided by the university were divided into those related to academic staff, the study programme, students, the organisation of classes and the university's infrastructure.

Figure 1 shows respondents' average ratings of factors related to academics.

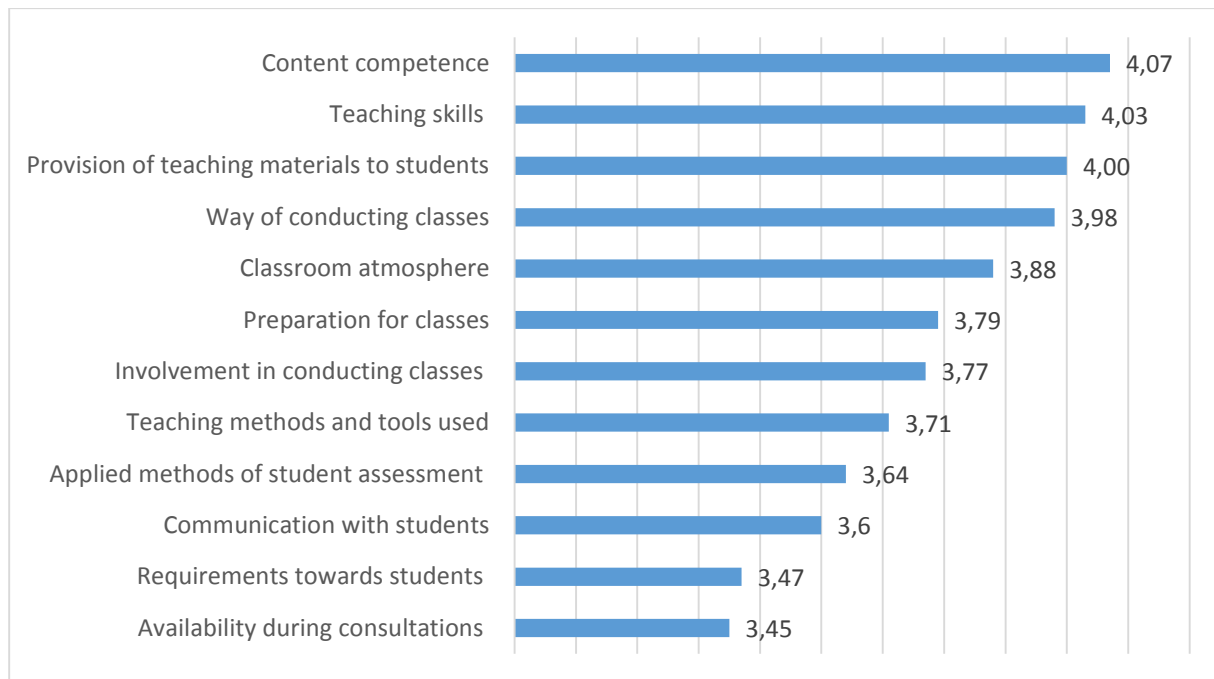


Figure 1. Respondents' opinions on the impact of factors related to academics on the quality of education.

Source: own elaboration.

In the opinion of the majority of respondents, all factors related to the academic staff determine the quality of education and student satisfaction with the courses - for each factor a total of more than 55% of indications were found: rather influences and definitely influences. Three factors, such as the substantive competence of teachers, the ability to transfer knowledge and making teaching materials available to students, received an average rating of 4 and above, which proves that they significantly affect the students' perception of the quality of services provided by the university.

According to the students, the greatest influence on the quality of education is the content competence of the academic staff, their knowledge and experience (4.07). Similar results were obtained by Madziała and their team (2023), who showed that professionalism and a high level of theoretical and practical preparation of people conducting classes are very important for students. Also, the results of the studies by Wójcik (2017) as well Akareem and Hossain (2016) confirm that the factor that most strongly determines students' perceptions of the quality of education is the content preparation and knowledge of the teachers. Szeliga-Duchnowska and Szewczyk (2019), on the other hand, showed that the content competence of teachers is perceived by students as an essential (mandatory) feature of the teaching service that must absolutely be provided, as its lack significantly affects student dissatisfaction. Slightly different results were obtained by Malik and their team (2012), who demonstrated that for business school students in Pakistan, the competence of lecturers is only the sixth most important factor (out of 48 assessed) in determining the quality of education.

Slightly lower, but also important for students, are the teachers' teaching skills - imparting knowledge and explaining issues in a simple and understandable way (4.03). Such a result is consistent with the results obtained by Hall (2011), who showed that the ability of academic staff to impart knowledge is, next to the knowledge of teachers, one of the most important factors determining students' satisfaction with the quality of education. Similar results were obtained by Malik and their team (2012) and Douglas and her team (2006), who demonstrated that, for students in Pakistan and the UK, teachers' didactic competence significantly determines the satisfaction with their classes.

Students also attach great importance to the teaching materials made available to them by the teachers, e.g. lecture presentations or additional studies (4.00), the way the classes are conducted, which should be interesting and engaging (3.98), the atmosphere in which the classes take place, including the teachers' approach to the students (3.88), and the teachers' preparation for the classes (3.79). As Douglas and her team (2006) have shown, making additional materials available is also very important for UK students.

In the respondents' opinion, factors such as the involvement of lecturers in conducting classes (3.77), teaching methods and tools used by lecturers, such as multimedia presentations, case studies, teamwork (3.71), applied methods of student assessment (3.64) and communication between teachers and students (3.60), are less important to ensure the quality of education.

In turn, the factors that are the least important for students are the lecturer's requirements towards students (3.47) and the availability of teachers during consultations (3.45).

The key components that universities need to consider in order to meet the expectations of the modern student are the transparency and clarity of study programmes, their uniqueness, innovation and integration with professional practice, as well as flexibility and stability (Kocot Kwasek 2024). Respondents' average ratings of factors related to the study programme are shown in Figure 2.

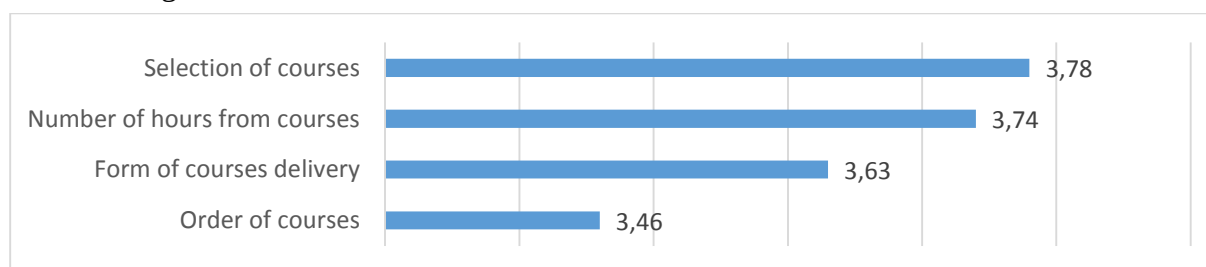


Figure 2. Respondents' opinions on the impact of factors related to the study programme on the quality of education.

Source: own elaboration.

In the group of factors related to the study programme, all of them received an average score of less than 4. However, it should be noted that most students perceive them as determining the quality of education (for each factor a total of more than 59% of indications were found: rather influences and definitely influences). The selection of courses (3.78) and the number of hours

from courses within the study programme (3.74) were found to be of greatest importance to respondents.

In the opinion of students, the form in which the courses are delivered, e.g. lectures, exercises, laboratories, project, determines the quality of education to a slightly lesser extent (3.63). The importance of forms of implementation for students was the subject of Wójcik's research (2017), which showed that the most effective forms of implementation of classes are considered by students to be laboratories and exercises that enable them to acquire practical skills. The less effective form of delivery, according to students, is lectures and the least effective - seminars.

The factor that least determines students' perceptions of the quality of the educational service provided by the university is the order of the courses taken in each semester of study (3.46).

Respondents were also asked to assess how the quality of education is determined by the students themselves (Figure 3).

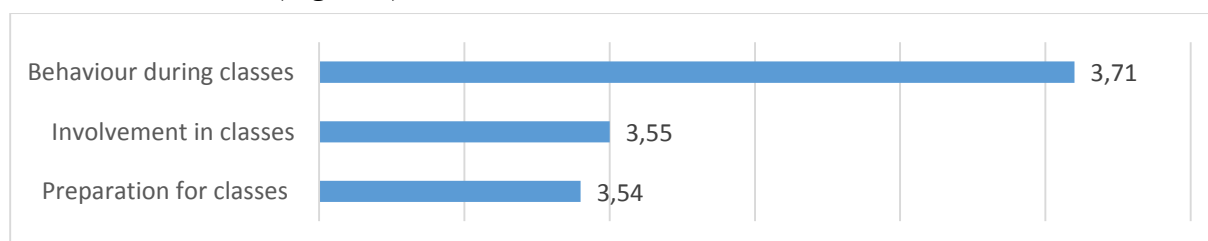


Figure 3. Respondents' opinions on the impact of student-related factors on the quality of education.

Source: own elaboration.

According to the respondents, the quality of education is most affected by the behaviour of the students in class (3.71). Less important is the involvement of students in classes, e.g. their activity during lectures, willingness to perform tasks during exercises and laboratories (3.55), and preparing students for classes (3.54). This is confirmed by the results obtained by Gos (2015), who, surveying students at a Polish university, showed that their degree of commitment to systematic preparation for classes is average.

Another group of factors assessed by the students was related to the organisation of the classes (Figure 4).

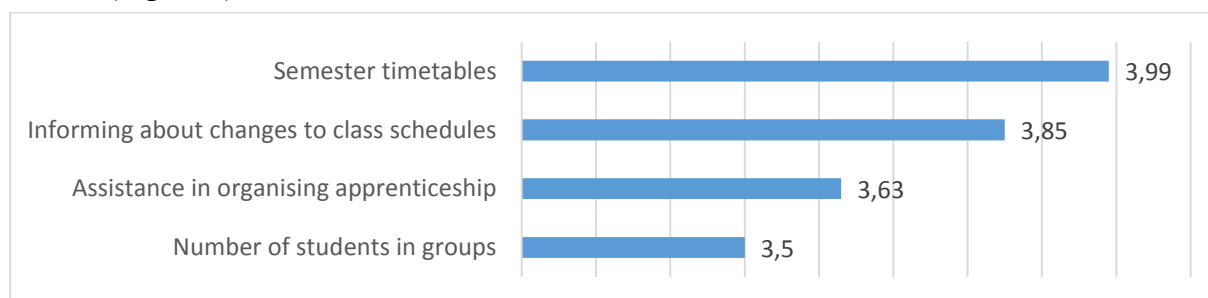


Figure 4. Respondents' opinions on the impact of factors related to the organization of the classes on the quality of education.

Source: own elaboration.

Among the factors related to the organisation of classes, semester timetables, including the times at which classes are held and the lack of breaks between classes, are the most important in ensuring student satisfaction with the quality of education (3.99). Similar results were obtained by Hall (2022), who, in a survey of students at four public technical universities in Poland, showed that the timetable of classes was the most important of the 25 factors identified by the author as determining students' satisfaction with the quality of education. In contrast, different results were obtained by Mailk and their team (2012), who demonstrated that for business school students in Pakistan timetables were the least important factor influencing their satisfaction with their studies.

According to the students, the quality of education is also determined to a large extent by the fact that they are informed effectively and well in advance of changes to their schedules (3.85). Slightly less important to them is the assistance provided by the university in organising apprenticeship, including help in finding a company where students can do their placement (3.63). In turn, the size of the student groups in which classes are held is of least importance (3.50). Similar results were obtained by Malik and their team (2012).

The quality of education can also be seen through the prism of the university's infrastructure. The results of the students' assessment of the infrastructure factors are shown in Figure 5.

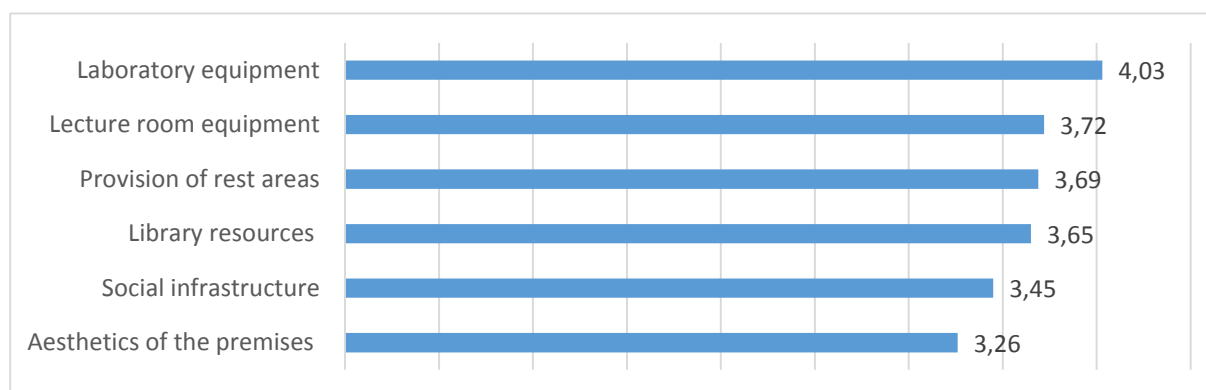


Figure 5. Respondents' opinions on the impact of factors related to university's infrastructure on the quality of education.

Source: own elaboration.

While evaluating factors related to the university's infrastructure, students indicated that laboratory equipment had the greatest impact on the quality of education (4.03). Wójcik (2017) also showed that among the factors related to the infrastructure, laboratory equipment significantly determines students' satisfaction with the quality of classes. Lecture room equipment are also of great importance to respondents (3.72). Similar conclusions were reached by Madziała and their team (2023), who demonstrated the importance of modern equipment used in the teaching process in achieving student satisfaction with the learning service. Similarly, Malik and their team (2012) showed that computer lab facilities are the second most important factor in terms of importance (after library resources) in determining the quality of education according to business school students in Pakistan.

According to respondents, the quality of education is also influenced by the university's provision of rest areas (3.69) and library resources (3.65). Gos (2015) in his research showed that students make little use of the library or reading room, which may be due to the fact that they are increasingly using online resources. In addition, students are limited to reading only the compulsory literature on the subjects studied. In contrast, Malik and their team (2012) showed that business school students in Pakistan rank access to library resources as the most important determinant of their satisfaction with their studies.

Students' satisfaction with the quality of service provided by the university is least influenced by the social infrastructure, such as access to the canteen or toilets (3.45), as well as the aesthetics of the premises (3.26). Similar results were obtained by Malik and their team (2012) and Douglas and her team (2006).

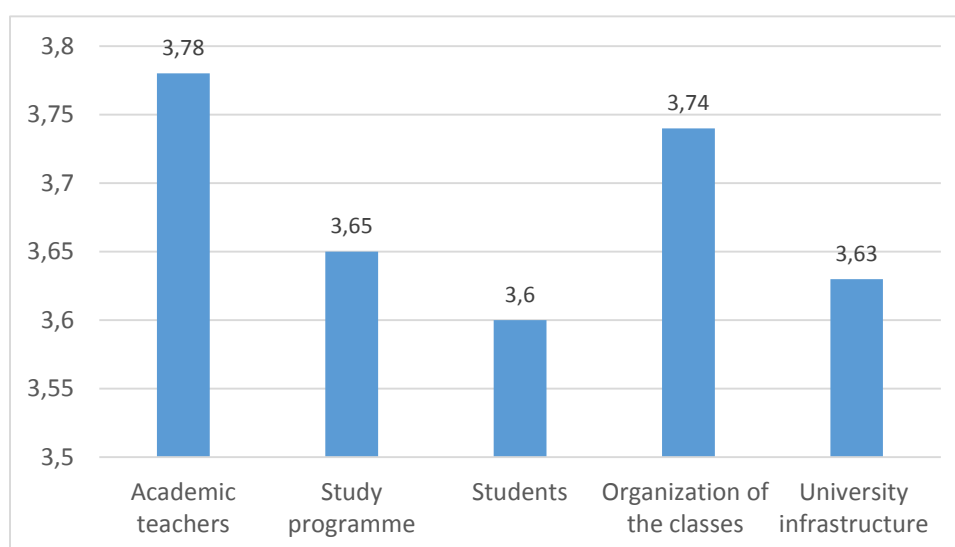


Figure 6. The importance of factors determining the students' perception of the quality of education divided into areas.

Source: own elaboration.

Analysing the results obtained at the level of individual areas (Figure 6), it can be concluded that student satisfaction with the quality of education is most influenced by factors related to academic staff (3.78). Wójcik (2017) and Hall (2011) also confirmed that the quality of education is most strongly determined by factors related to teaching staff, such as the content-related, methodological and communicative competences of teachers, their commitment to their work and their positive attitude towards students. Gos (2015) also counts teachers among the most important factors influencing the quality of education, and Adamska (2018) showed that, according to students, teaching staff is the most important factor shaping the image of a university.

Student satisfaction with the quality of education is also significantly determined by factors related to the organisation of the classes (3.74). Factors related to the study programme (3.65) and the university infrastructure (3.63) are less important for the respondents. In contrast, how students perceive the quality of education is least determined by student-related factors

(3.60). In her research, too, Wójcik (2017) showed that, of the parties involved in ensuring the quality of education, students feel least responsible for this quality. It can therefore be concluded that although students recognise the impact of their attitudes on the quality of education, they consider them to be the least important in terms of influencing the teaching process.

In recent years, an increasing challenge for universities has been the quality of classes delivered using distance learning means (Roszczynialski, 2020). Irrespective of the teaching method, it is the university's task to provide quality education, however, it is widely assumed that distance learning is less effective compared to education delivered in traditional form (Czapiewska, 2021). One of the themes undertaken in the survey was to find out what form of instruction is preferred by students (Figure 7) and how students perceive the forms of delivery in terms of their impact on the quality of education (Figure 8).

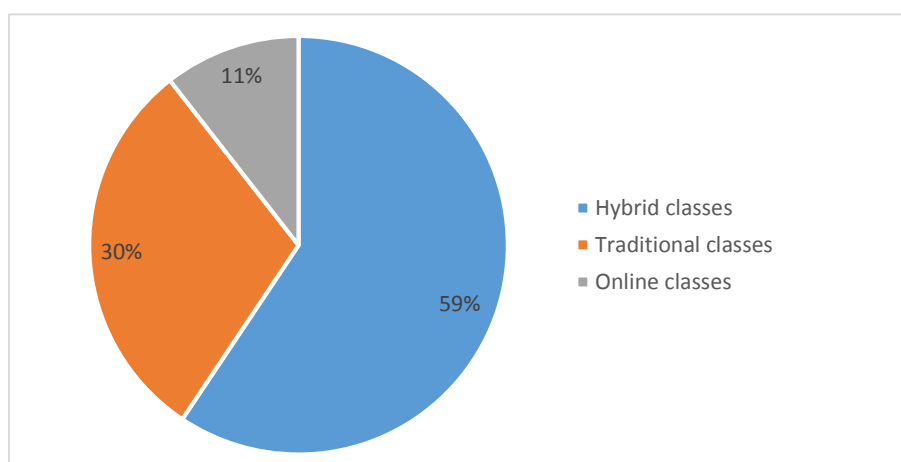


Figure 7. Respondents' preferences for the form of delivery of the course.

Source: own elaboration.

Most of the students participating in the study (59%) prefer a hybrid form of classes, including the implementation of lectures using distance learning means, and the other types of classes in the traditional form in direct contact between students and academic teachers. Every third respondent prefers classes in the traditional form, and only 11% are in favor of classes carried out remotely. This approach is consistent with the results obtained by Tuczyński (2021), who showed that replacing part of a traditional class with remote teaching has a positive effect on the satisfaction of the class participants.

It is important to note that the survey conducted in connection with this paper did not ask the students of FMQS GMU about the reasons for preferring the hybrid form of education. Identifying the factors that determine the quality of this form of instruction, as well as differences in student preferences depending on the topic or type of instruction, may be a direction for further research. However, as Geng and the team (2019) point out, the acceptance of distance learning may be due to the fact that students perceive it through the lens of learning independence, a sense of responsibility for learning and satisfaction with learning. In addition,

as Ali (2020) points out, contemporary students are hooked on mobile technology and expect technology-integrated learning, as it enables them to catch up with their studies at home. The research conducted so far on the perception of remote classes by students also proves that among the benefits of such classes noticed by students, the most important are time savings, the possibility of studying far from home, the possibility of combining work and study, reduced costs of travel to university, convenience, flexibility of study time, development of digital competences, the possibility of adapting the pace of learning to their needs, the possibility of learning information and communication tools, as well as the possibility of better planning and organizing studies, work and personal life (Ober, Kochmańska, 2022; Geng, Law, Niu, 2019; Bali, Liu, 2018; Zheng, Bendera, Lyon, 2021).

Online classes, which are becoming increasingly common in universities, are associated with flexibility and convenience of study, saving time and reducing the costs spent on commuting to university. However, this does not mean that students are willing to abandon traditional classes altogether. Similar results were obtained by Roszczynialski and Kijanka (2020), who, when examining the opinions of students at one of the non-public universities in Poland on distance learning, showed that students are in favor of a form of education where distance learning does not replace, but is complementary to traditional education. A similar position is presented by Czapiewska (2021), who states that distance learning mechanisms should be a permanent element complementing, but not replacing, full-time education at a university. Furthermore, the author indicates that students declare a greater acceptance of online lectures than practical classes (exercises, laboratories, seminars).

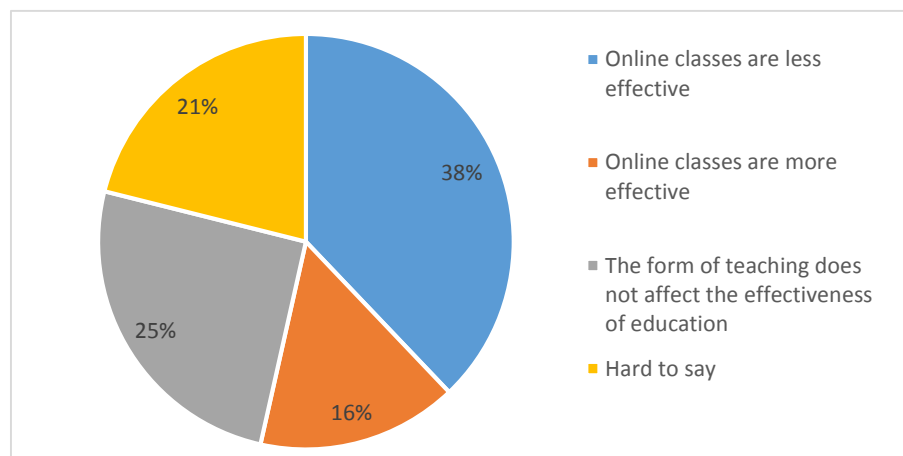


Figure 8. Respondents' views on the effectiveness of classes delivered online.

Source: own elaboration.

Remote learning, as an alternative to traditional education, should ensure the same quality and effectiveness of education, thus meeting the expectations of students and enabling them to achieve the same learning outcomes (Roszczynialski, 2020). However, it is generally assumed that distance learning is by definition inferior in quality to that delivered in a classroom-based format, so traditional teaching cannot be completely replaced by distance learning, especially

in the case of forms of teaching where direct contact between students and teachers is essential (laboratories, exercises) (Roszczynialski, 2020; Czapiewska, 2021). These views are corroborated by the results of the study conducted as part of the work - the majority of respondents (38%) perceive classes delivered remotely as less effective in achieving the intended learning outcomes compared to the traditional form of education. For 25% of the respondents, the form of conducting classes is irrelevant, and 21% were unable to express their opinion in this regard. Only 16% of respondents perceive remote classes to be more effective compared to classes delivered onsite.

According to the survey, student satisfaction with their studies is a complex and multidimensional issue. Meeting students' requirements relating to the quality of education is particularly important in terms of maintaining their loyalty and encouraging them to continue their studies at subsequent levels. Therefore, the collection of students' opinions on the level of their satisfaction using periodic evaluation surveys is insufficient for the correct identification of directions for the improvement of the educational processes implemented by universities. This is because such measures are limited to assessing the quality of teaching and the work of academic staff, and as the survey shows - student satisfaction is determined by a number of factors (both didactic and non-didactic) that have different meanings for students. Therefore, a component of any internal educational quality assurance system implemented in universities should be a formalised policy for systematically surveying students' perceptions of the importance of factors influencing their satisfaction with their studies and using the results to improve university operations.

The conducted study made it possible to achieve the aim of the work and to positively verify the research hypothesis. It was confirmed that individual factors determine the quality of education and student satisfaction with the services provided by universities to varying degrees. Activities related to the improvement of didactic processes should be focused on factors of the greatest importance for students.

The study undertaken in this thesis should be continued. It is reasonable to widen the research sample - to include students representing various universities in Poland, educating in different fields and profiles of study. This approach will make it possible to identify differences in perceptions of educational quality depending on the subject matter or type of course. Furthermore, due to the changing conditions of the market for educational services in which universities operate, research should be repeated from time to time in order to identify changes in students' perceptions of the determinants of educational quality over time and to flexibly adapt the educational service to the requirements currently relevant to students. Furthermore, with the growing importance of distance learning, another potential line of research could be to assess students' perceptions of the factors determining the quality of this form of classes.

4. Conslusions

Students, as recipients of an educational service, determine the required level of quality of that service. They should therefore be seen by modern universities as their most important stakeholder, and a commitment to meeting students' requirements relating to educational quality should be a key element of the university's strategy and quality-based organisational culture. An integral element of such an approach is the systematic examination of students' needs and expectations regarding the quality of education, as well as their opinions on the factors determining this quality. Knowledge of how students perceive the quality of teaching services is essential for university management and all staff involved in the delivery of educational processes, in order to properly identify and implement measures to increase student satisfaction with the services provided by universities, and thus increase its competitiveness in the market for educational services.

Based on the results of the survey, the following conclusions can be drawn:

1. The factors shaping the quality of the educational service, related to the academic staff, the study programme, the students, the organisation of classes and the infrastructure of the university, determine the satisfaction of the students of FMQS GMU with the services provided by the university to varying degrees.
2. When planning and implementing improvement activities, FMQS GMU should prioritise the elements of the education service related to academic staff. These activities should be focused on the development of substantive competences of teachers and their ability to transfer knowledge, as well as the improvement of didactic materials made available to students, supporting the learning process. WZNJ UMG should also improve the laboratory infrastructure used in the delivery of the courses.
3. Students of FMQS GMU prefer the hybrid form of course delivery; however, they perceive courses delivered remotely as less effective compared to those delivered in the traditional form. Therefore, when implementing measures to improve the quality and effectiveness of classes delivered remotely, FMQS GMU should develop the competence of academic teachers in the delivery of classes using distance learning means, as well as improve the tools used in this form of classes.
4. As part of the internal educational quality assurance system implemented at FMQS GMU, rules should be developed and applied for periodically surveying students' opinions on factors determining their satisfaction with the quality of teaching services offered by the Faculty. These results should be made available to students, Faculty management, academic staff and Faculty staff involved in the planning and implementation of learning processes.
5. In order to increase student satisfaction, the Faculty should take measures to increase student participation in the planning and organisation of teaching processes.

The obtained results are of theoretical importance, as they complement the knowledge about the determinants of the quality of education and their significance for students. Research to date has focused primarily on assessing students' satisfaction with the quality of education and less on identifying the determinants of this quality from the students' perspective. The results can also have practical applications - they can be used by universities to identify and implement measures to improve the quality of the educational services provided.

However, the results obtained can be used not only at the level of universities, which, by improving their educational services, can increase their ability to meet the requirements of students, increase their satisfaction and loyalty, and thus shape a positive image in the market for educational services. The obtained results also have a number of implications for other parties interested in the quality of education:

1. From the point of view of the state, they can support the development of the competitiveness of Polish universities and foster confidence in the national higher education system. As students are the main beneficiaries of the education system, their opinions should be the basis for shaping national education policy. Taking into account the results obtained, the assumptions of this policy should include, first and foremost, activities related to improving the teaching competences of academic staff, ensuring that students develop their key competences adapted to the needs of the labour market, as well as activities related to subsidising laboratory infrastructure used in the teaching process.
2. From the point of view of the Polish Accreditation Commission, they can be helpful in determining the directions of potential changes in accreditation standards and support the processes of periodic evaluation of the quality of education at universities. Both the accreditation standards and the evaluation carried out by the evaluation teams should emphasise the development by universities of those elements of the teaching process that are of greatest importance for students.
3. From the point of view of the labour market, they can support employers in attracting graduates with the competences necessary to meet the current and future needs of the economy.

When analyzing the results of the conducted study, one should be aware of the limitations associated with them. The survey was conducted among students of only one university, hence the results cannot be generalised to the entire student population in Poland. However, they can constitute the basis for identifying some trends in how students perceive the quality of educational services provided by universities. The inclusion in the survey questionnaire of a wide range of factors determining the quality of education, which were assessed by the survey participants, should be considered a strength of the study. At the same time, attention should be paid to certain limitations resulting from the measurement tool used and the data analysis method. In the case of the measurement tool, an ordinal scale was used, which is characterised by certain limitations, primarily related to the respondents' avoidance of extreme answers,

subjective interpretation of the scale degrees and the lack of in-depth answers of the respondents – the study did not include justification by students why they perceive the impact of individual factors on the quality of education in this way. On the other hand, considering the method of data analysis, only descriptive statistics methods were applied without the use of statistical inference methods. Therefore, further research in this area is justified. Extending the research sample and conducting surveys in different universities is also justified in the context of identifying whether perceptions of the determinants of educational quality differ according to the field of study, profile and level of study.

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COOPETITION IN THE BANKING SECTOR IN RESONSE TO CYBERTHREATS

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Purpose: The purposes are the analysis of coopetition in the Polish banking sector as a response to cyber threats and legal regulations. Identification of the causes of coopetition in the Polish banking sector in terms of increasing cyber resilience. Identification and analysis of key forms of coopetition in the area of cybersecurity.

Design/methodology/approach: The paper addresses a contemporary and critical challenge faced by the Polish banking sector: the need to collaborate on cybersecurity despite being direct competitors. This approach is not purely theoretical. It seeks to provide actionable insights for industry practitioners and regulators.

Findings: The research creates a detailed map by identifying the most dangerous cyber threats, the most valued benefit, and the most critical barriers. This tripartite analysis offers a comprehensive and practical view of the coopetition landscape.

Research limitations/implications: The study's primary limitations include its focus on the Polish banking sector, which may limit the generalizability of the findings to other countries with different regulatory environments and market structures. Longitudinal case studies tracking existing coopetition initiatives over time would provide invaluable insights into their long-term effectiveness and evolution.

Practical implications: The primary practical implication is that Polish banks should strategically develop formalized coopetition structures, such as information-sharing system, to enhance collective cybersecurity. This cooperation will directly impact the business by reducing financial losses and regulatory fines, while strengthening customer trust.

Social implications: The findings can inform both industry policy by encouraging the creation of formal threat-sharing platforms and public policy by shaping regulations, that incentivize secure collaboration over pure competition.

Originality/value: It is one of the first empirical investigations into the drivers, benefits, and barriers of cybersecurity coopetition specifically within the Polish banking sector. The value is for banking executives, cybersecurity professionals and policymakers.

Keywords: Banking sector, cybersecurity, coopetition, cyberattacks, legal regulations.

Category of the paper: Cybersecurity research within the banking sector coopetition as a response of syber threats and legal regulations.

1. Introduction

The banking sector, which is of key importance to the economy, is a prime target for cybercriminals. The rapid growth of digitalization, the processing of sensitive data, and the potential for financial and reputational losses make banking institutions an attractive target. Traditional, isolated security models, relying solely on internal investments in technology and personnel, are proving insufficient in the face of organized, transnational criminal groups using advanced techniques such as Advanced Persistent Threats (APT) and ransomware attacks. In response to the increasing sophistication of cyber threats and the resulting legal regulations, a strategy has been developed for cooperation between competing banking entities in selected specialist areas where the synergistic benefits outweigh the costs of competition. In the context of cybersecurity, coopetition manifests itself in the sharing of threat intelligence, the development of standards, joint training, and investment in advanced detection and response systems. Banks increasingly need to embrace coopetition system between them and collaborate even as competitors to strengthen collective defenses against escalating cyber threats. Such joint efforts enable faster threat detection, shared intelligence, and more resilient financial systems.

The main objective of this article is to analyze the phenomenon of coopetition in the Polish banking sector as a response to cyber threats and legal regulations. The specific objectives are:

- To identify the causes of the coopetition phenomenon in the Polish banking sector in increasing the level of cyber resilience.
- To identify and analyze key forms of coopetition in the area of cybersecurity.
- To determine the barriers and benefits resulting from coopetition in the banking sector.

The research hypothesis is: Cyber incidents and associated legal regulations have contributed to the undertaking of cooperative activities in the banking sector. The research questions are:

- What types of cyberattacks may cause the undertaking of coopetition in the banking sector in response to cyber threats?
- Which legal regulations (EU and national) stimulate and which hinder the development of coopetition in the cybersecurity of the banking sector?
- What could be the benefits of coopetition in the banking sector in the context of cybersecurity?
- What could be the barriers to implementing coopetition in the banking sector in the area of cybersecurity?

The phenomenon of coopetition in banking is becoming increasingly important, especially in the context of growing cyber risk and regulatory requirements. It is a strategy, that allows banks to operate beyond the boundaries of competition for the common good of the system.

The banking sector, as the foundation of the economy, remains one of the main targets of cybercrime. The growing digitization of services, the processing of sensitive customer data, and the high potential financial and reputational losses make financial institutions particularly vulnerable to attacks such as ransomware or advanced, long-term APT operations. Traditional, isolated protection models based solely on internal technology and human resource investments are becoming insufficient in the face of the scale and complexity of today's threats (Santos et al., 2025; Prasad et al., 2025).

In response to this situation and regulatory pressure (including EU frameworks such as NIS2 and DORA), a model of coopetition (cooperation between competitors) is developing, which in the area of cybersecurity is materializing, among other things, through the sharing of threat intelligence (CTI), the creation of technical standards and procedures, joint exercises/training, and investments in advanced detection and response systems. Such partnerships enable faster threat detection, consolidated responses, and increased resilience of the entire financial system. At the same time, coopetition requires balancing the benefits of synergy against the costs associated with losing competitive advantage and the risk of disclosing sensitive information (Chang, Huang, 2023; Harasim, 2021).

In addition, EU regulations aimed at harmonizing digital resilience requirements, primarily the Digital Operational Resilience Act (DORA) and the updated NIS2 directive, strengthen incentives for cooperation between banks and between banks and supervisory authorities. These regulations not only impose obligations related to ICT risk management and incident reporting, but also encourage the creation of information sharing mechanisms and common supervisory standards. However, the implementation of these regulations also involves practical barriers: supervisory divergences, compliance costs, and legal uncertainties regarding data protection and competition (Buttigieg, Zimmermann, 2024; Singh, 2023).

From an empirical and theoretical perspective, the literature provides evidence that the coopetition model can increase the cyber resilience of the sector by accelerating the exchange of threat intelligence and pooling resources for rapid response. However, research also points to significant barriers: insufficient standardization of CTI formats, lack of trust between entities, and difficulties in determining incident reporting thresholds, which hinder effective cooperation. These problems also point to areas for further research and practical intervention (Santos et al., 2025; Schmitz-Berndt, 2023).

In light of the above, the main objective of the article, to analyze the phenomenon of coopetition in the Polish banking sector as a response to cyber threats and regulations, is justified and necessary. The study aims to determine the causes of this phenomenon, identify key forms of cooperation in the area of cybersecurity, and recognize the barriers and benefits of such cooperation, particularly in the context of legal requirements in force in the EU and Poland (Fuszder et al., 2025; Waizel, 2023).

2. Methods

The methodological approach of this study is based on a qualitative analysis of existing sources and empirical data collected through a survey. The research procedure consisted of two main stages. First, a comprehensive analysis of the subject literature, case studies of cyber incidents in the banking sector, and the applicable legal framework at both the EU and Polish national levels was conducted. This included regulations such as the GDPR, NIS2 Directive, DORA Regulation, the Act on the National Cybersecurity System, the Banking Law, and the Act on Competition and Consumer Protection. This stage allowed for the identification of the theoretical and legal context of coopetition. Subsequently, empirical research was carried out. Initially, interviews were conducted with representatives of seven banks operating in Poland to establish research criteria. Following this, research surveys were distributed to employees of these banks. The study involved 107 respondents working in departments dealing with fraud prevention, cybersecurity, compliance, and IT security engineering.

The survey utilized a 5-point Likert scale for responses. For assessing causes, benefits, and barriers, the scale was: 1 – Completely Insignificant (CI), 2 – Slightly Insignificant (SI), 3 – Neutral (N), 4 – Significant (S), 5 – Very Significant (VS). For assessing the severity of cyberattacks and their consequences, the scale was: 1 – Very Low (VL), 2 – Low (L), 3 – Medium (M), 4 – High (H), 5 – Very High (VH). For assessing the benefits of coopetition, the scale was: 1 – No Benefit (NB), 2 – Slight Benefit (SB), 3 – Moderate Benefit (MB), 4 – Major Benefit (MB), 5 – Very Major Benefit (VMB).

The collected data were analyzed using descriptive statistics, including the calculation of mathematical average (MA) and standard deviations (SD), and the distribution of responses was presented in percentage terms.

3. Literature review

In recent years, the digital transformation of the banking sector has significantly increased the convenience and efficiency of financial transactions. However, this transformation has also contributed to a significant increase in cybersecurity threats that jeopardize the integrity, confidentiality, and availability of banking systems and customer data (Ovewole et al., 2024). Technology plays a key role in various areas of life, especially in the banking sector. The dynamic development of technology has effectively streamlined the functioning of the banking sector and financial services institutions, causing a fundamental change in the way the banking sector operates, which has provided banking institutions with many opportunities to raise and improve the level of services provided to customers (Shehab et al., 2024).

3.1. Cybersecurity in the banking sector

Business objectives related to cybersecurity in banks focus on marketing and sales, as well as services, to ensure secure and trustworthy operations. In terms of marketing and sales, banks strive to update customer information programs with new threats (Tran, 2025). Cybersecurity is a process aimed at protecting computers, servers, networks, and digital data from unauthorized access, destruction, or attack in cyberspace. The goal of businesses and governments in ensuring an adequate level of cybersecurity is not only to protect confidential data, but also to ensure its availability while maintaining its integrity (Al-Alavi, Al-Bassam, 2020). The banking and finance sector faces a triple challenge in cybersecurity, aptly named the cybersecurity triangle. This triangle encompasses three interrelated aspects: high-value targets, complex IT infrastructure, and stringent regulatory requirements. Each of these issues exacerbates the others, creating an exceptionally difficult environment for cybersecurity professionals in the financial sector (Reddem, 2024). Ensuring cyber resilience in banks is one of the greatest challenges of our time due to the continuous development of technologies that create cyber threats. Cybersecurity can be systemic in nature in certain cases. An attack on one institution can have a domino effect and undermine confidence in the entire banking sector. For this reason, banks work together to prevent attacks from spreading, respond quickly to threats, and strengthen the stability of the financial system as a whole. The main reasons for this cooperation are increasingly complex cyber threats and legal regulations.

3.2. Causes of coopetition in the banking sector – cyberattacks

Cyberattacks on the banking sector are currently characterized by a high degree of specialization and continuous evolution. Increasing the level of security requires a comprehensive, multi-layered approach that combines advanced technologies, regular training, cooperation within the sector, and cooperation with law enforcement agencies. Attacks on the banking sector are evolving from simple fraud to sophisticated, advanced persistent threats (APTs) that exploit gaps in technology, processes, and human error.

Advanced persistent threats (APTs) are one of the main cybersecurity issues that have emerged this decade. They can be defined as long-term, sophisticated activities that are covert and remain undetectable for a long time (Hasan et al., 2023). ATP attacks are typically organized by well-funded and organized cybercriminal groups or state actors to gain unauthorized access to sensitive systems. ATP cyberattacks steal sensitive data, maintain a long-term covert presence on the target network, or destroy the system they infect (Nelles et al., 2024). When using APT, attackers employ a variety of tools to ensure that cyberattacks remain undetected within the target network for months or even years (Mat et al., 2024). Attackers search for security vulnerabilities in order to bypass detection systems, and continuously modify their malware to circumvent intrusion detection systems (Krishnapriya, Singh, 2024).

DDoS (Distributed Denial of Service) attacks involve preventing users from accessing an online service, most often through temporary disruptions or suspension of the hosting service. These attacks may be aimed at disrupting the operation of a critical system or interrupting connectivity, resulting in denial of access to services for users of the targeted resources (Tripathi et al., 2020). DDoS attacks are a common form of cyber aggression aimed at disrupting the normal functioning of targeted online services (Merkebauly, 2024). The main components of DDoS attack architecture typically include command and control infrastructure, a network of compromised devices (botnets), a traffic generation mechanism, and techniques to amplify the impact on the attacker's resources (Khaund, 2025).

Ransomware is a type of malware that locks down a system, preventing users from accessing the system or specific files. The attacker then demands a ransom in exchange for restoring access. If the victim does not pay the ransom within a specified time frame and amount, the data will be lost (Aggarwal, 2023). The most common vectors for ransomware attacks are phishing, exploiting vulnerabilities in outdated services, or inadequately secured remote access (KNF CSIRT, 2024).

Ransomware-crypto encrypts files and data on the victim's computer or mobile phone. Once installed on the system, this type of software invisibly searches for files and data. Ransomware-locker attacks end-user systems or mobile devices. It can lock the input interface, such as the keyboard and mouse, preventing the user from accessing the device. Master boot record-ransomware encrypts the MBR table, which contains information about the organization of logical partitions containing file systems. Encrypting the MBR table makes it impossible to find files on the hard drive (Hoseini, 2020). With ransomware attacks, perpetrators can affect not only large organizations, but also small and medium-sized entities (Sudheer, 2024).

Living-Off-The-Land (LOTL) – cybercriminals devote a lot of time to trying to deceive and circumvent advanced malware detection algorithms. A particularly interesting method is the use of binary files and tools that are often part of the basic distribution of the operating system (OS). Because this technique uses elements already present in the system, it is called “living off the land” (Boros et al., 2022). Despite the widespread availability of heuristic rule-based detection methods, these systems often fail to detect new or hidden threats, especially those using LOTL techniques. These threats use legitimate software to perform malicious actions, blending in with harmless system behavior (Trizna et al., 2024).

Man-in-the-Browser (MitB) attack aims to intercept data transmitted as part of secure communication between the user and a web application. The Trojan embeds itself in the user's browser and can be programmed to activate when the user accesses specific websites, such as online banking sites. Once activated, the MitB Trojan can intercept and manipulate information sent by the user in real time (Ayyagari, 2017). Man-in-the-Browser malware is based on browser extensions, which are a target for attack because browser extensions have access to sensitive data such as usernames and passwords (Tong, Nwokeji, 2023).

An attack on SWIFT refers to deliberate, malicious activities aimed at stealing money or disrupting operations by compromising the SWIFT (Society for Worldwide Interbank Financial Telecommunication) system. Criminals have carried out a series of successful cyberattacks on the global banking system through this system. One of the most notorious attacks was a fake transfer of \$81 million from the central bank of Bangladesh in February 2016. The hackers introduced malware into the bank's server to steal login details for the SWIFT communication system. They then successfully covered up the traces of their infiltration by removing evidence from printed SWIFT messages in real time (Liu, 2021).

Digital skimming is a type of cyberattack in which criminals install malicious code (usually a so-called skimmer) on a store's website or other platform in order to steal users' payment or personal data. Europol defines digital skimming as "the act of stealing credit card or payment card information from online store customers. Transaction data is intercepted during the online purchase process, and customers do not notice anything unusual. Digital skimming attacks are also known as internet skimming, online card skimming, e-skimming, formjacking, or magecart" (EUROPOL, 2024). Skimming is not limited to physical, man-made devices. This crime can also be software-based. Silent skimmers are threats, that infiltrate payment systems and steal payment information using Python (Ciaccio, Onat, 2025).

A key threat to banks, though not necessarily technical, is phishing attempts that aim to obtain usernames, passwords, and credit card details in the banking sector. Phishing involves impersonating a credible website and making official-sounding statements. Phishing attacks take various forms that deceive victims: emails, phone calls, website impersonation, and social media posts (Yuspin et al., 2024). Phishing and social engineering are the two most popular attack vectors. Phishing attacks targeting specific customers account for the largest share of these attacks. In most cases, customers themselves are contacted by hackers to verify information about their bank accounts. Bank employees have also become targets of these attacks, especially after the increase in remote working during the pandemic (Khemka, 2024).

Cyberattacks are currently one of the most serious challenges facing the financial sector. Although their direct effects (such as financial losses or data loss) are obvious, they have a profound and multidimensional impact on the very nature of competition between banks. Instead of supporting innovative competition, cyber threats can stifle and distort it. Attacks in cyberspace can therefore influence cooperation between banks despite their simultaneous competition in the sector.

3.3. Causes of coopetition in the banking sector – UE regulations

The GDPR (Regulation 2016/679) imposes an obligation to ensure the security of personal data processing (Article 32). This encourages banks to cooperate on best practices. At the same time, provisions on consent, confidentiality, and the legitimacy of processing can complicate the free exchange of information about incidents, especially if they contain personal data. In many cases, personal data is a vector for cybercriminals, as it can be used at a later time to

prepare/commit further/other crimes (Official Journal of the UE, 2016). The NIS2 Directive, transposed in Poland in 2024 (Official Journal of the UE, 2022), includes financial sector participants in the scope of “important” and “key” entities. It obliges them to implement risk management measures and report significant incidents to the competent authorities (CSIRT MON, CSIRT NASK). This directly creates an environment for coopetition between the sector and the regulator. It is worth adding here, in the context of key cyber threats, that Article 21(3) of the NIS2 Directive defines a serious computer security incident as an incident, that (Kapica, Rosiak, 2024):

- has caused or may cause severe operational disruption of services or financial losses for the entity concerned,
- has affected or is capable of affecting other natural or legal persons, causing significant material and non-material damage.

The DORA, Digital Operational Resilience Act (EU, 2022), regulation, as a key act in considering the implementation of a coopetition model in the banking sector, encourages the creation and participation in the sharing of information on cyber threats. It establishes a legal framework for such activities, aimed at overcoming legal concerns related to competition and data protection regulations. It also mandates regular resilience testing, which naturally evolves into joint interbank training.

3.4. Causes of coopetition in the banking sector – national legal regulations

The Act of July 5, 2018 (Act of a National Cybersecurity System, 2018), on the national cybersecurity system is a key piece of legislation implementing the EU NIS Directive into Polish law. Its main objective is to increase the level of digital security in the country, and the banking sector, as part of critical infrastructure, is subject to its particular rigor. Banks are required to implement technical and organizational security measures adequate to the identified risks. These measures must ensure the security of the data processed and the services offered. The purpose of the Polish Financial Supervision Authority's supervision of the financial market is to ensure the proper functioning of this market, its stability, security, and transparency, trust in the financial market, as well as to protect the interests of market participants, including through the provision of reliable information on the functioning of the market (Financial Supervision Authority, 2006). The Financial Market Supervision determined the organization, scope, and purpose of the KNF's activities. The Polish Financial Supervision Authority (KNF) plays a key role in the area of cybersecurity for banks operating in Poland, acting as a regulator, supervisor, and coordinator.

It is worth mentioning that, in addition to national regulations, the National Bank of Poland plays an important role as the central bank (bank of banks), which "performs regulatory functions in relation to banks, aimed at ensuring the security of deposits held in banks and the stability of the banking sector. It organizes the cash settlement system, conducts ongoing interbank settlements, and actively participates in the interbank money market. The National

Bank of Poland is responsible for the stability and security of the entire banking system, acts as the bank of banks, and supervises payment systems in Poland" (National Bank of Poland). The central bank is responsible, among other things, for macroprudential supervision to ensure the stability of the financial system or its key elements. This supervision is related to the activities of the Financial Stability Committee, which is a body operated by the National Bank of Poland and an office serving the Minister of Finance (Dmowska, 2022).

3.5. Legal regulations that may constitute barriers to the coopetition development

GDPR Regulation (EU) 2016/679: While Article 32 imposes an obligation to ensure data security, the principles of data minimization and purpose limitation can be interpreted as a barrier to the free sharing of incident details that may contain personal data. This requires the use of anonymization and aggregation techniques. With regard to the increasingly common use of ZTA (Zero Trust Architecture) in financial institutions, which is guided by the principle of “never trust, always verify” (Ramakrishna, 2025) and requires continuous verification of every user, device, and transaction, this type of approach may constitute a limitation in the context of cooperation with other banks.

Articles 104-105 of the Banking Law Act of August 29, 1997 refer to aspects related to banking secrecy. Violating it during the process of sharing information about an attack (which could reveal customer data) may result in criminal liability. This is the most serious legal barrier, which is overcome by strictly defining the scope of the information shared (only attack metadata, without sensitive data). Banking secrecy is not an obstacle to cooperation with supervisory/law enforcement authorities (KNF, KAS, Prosecutor's Office, Police) or in the context of reporting obligations. However, voluntary exchange with other commercial banks (i.e., competitors) requires a very cautious approach and often relies on general clauses of “statutory authorization” or “customer consent,” which are difficult to apply in practice.

With reference to the Act on Competition and Consumer Protection of February 16, 2007, uncontrolled cooperation between competitors, including banks, may raise concerns about bid rigging or the exchange of commercial information. Therefore, coopetition should be limited solely to security issues. The Act prohibits agreements that restrict competition. Close cooperation between competing banks, even in the area of cybersecurity, may raise suspicions on the part of the antitrust authority (UOKiK) that it is a front for illegal agreements in other areas (e.g., pricing, market). The exchange of overly detailed information on the costs of implemented security measures, planned investments, or internal procedures may be considered an exchange of sensitive information from a competition perspective.

3.6. Coopetition in the Polish banking sector in the context of cybersecurity

The concept of coopetition represents the dichotomy between competition and cooperation. Cooperative and competitive forces are fundamental components of business in this regard. The challenge associated with implementing coopetition is the exchange of information and

sharing of knowledge, which allows a company to assimilate its competitor's know-how (Kobiyh et al., 2025). Coopetition can be considered a key strategy in developing economies. Innovative activities related to research and development involve many risks and costs, and the coopetition strategy is one of the key factors that can be used in this situation (Salamzadeh et al., 2024).

In turn, coopetition in the banking sector in the context of cybersecurity consists of voluntary, formalized cooperation between banks to exchange information about threats (Threat Intelligence), best practices (implementation of data anonymization requirements), and anomalies detected on the basis of network traffic. Banks operating in Poland cooperate through the Polish Bank Association (ZBP), using joint response and coordination centers, through the Cybersecurity Threat Information Exchange Forum coordinated by the ZBP, or within the framework of international cooperation in European and global initiatives.

The Polish Bank Association is the main platform for cooperation within the Polish banking sector. In response to cybersecurity threats and incidents, as well as the needs of banks, on November 29, 2016, the Council of the Polish Bank Association, together with banks, established the ZBP Banking Cybersecurity Committee. FinCERT.pl operates within the Committee as an operational unit that collects, analyzes and transmits information on identified threats and criminal incidents within the banking sector, among others (The Polish Bank Association). Cooperation through the ZBP may include:

- threat intelligence sharing,
- developing standards and recommendations for electronic banking,
- organizing joint training courses on cyberattack simulation,
- representing the sector's interests before the regulator (KNF) and legislators.

Cyber Threat Intelligence (CTI) involves gathering and analyzing threat intelligence to support decision-making and help organizations respond effectively (Fieblinger, 2024). CTI is an integral part of the cybersecurity assurance process. Development in this area means responding to the ever-increasing sophistication of adversaries and helping to include new elements of cyber threats in the analysis process (Baraniuk, Marszałek, 2024). In the banking sector, CTI in the coopetition model is a strategic collaboration in which, instead of acting in isolation, banks strengthen their common defense against evolving cyber threats.

In the Polish banking sector, banks compete with each other for customers and market share, but at the same time they cooperate in the area of cybersecurity, because a common threat (cyberattacks) poses a systemic risk to the entire sector. The success of one bank in defense depends on the security of the entire ecosystem. The KNF CSIRT team, performing the tasks of the Sectoral Cybersecurity Team, in cooperation with entities of the national cybersecurity system, in particular national CSIRT teams, supports Key Service Operators in handling serious incidents and conducts activities aimed at analyzing other incidents (Financial Supervision Authority, 2006), blocking fraudulent domains of a fraudulent nature, and analyzing malware in the context of financial security (Mroczka, Groniewski, 2025).

The Banking Security Centers of the Polish Bank Association are specialized units whose purpose is to strengthen the resilience of the Polish banking sector to cyber threats through coordination, analysis, and response to incidents. In a report by ENISA (European Union Agency for Cybersecurity) dated February 14, 2018, FinCERT.pl, the Banking Cybersecurity Center of the Polish Bank Association, was recognized as the ISAC (Information Sharing and Analysis Center) of the Polish banking sector (Polish Bank Association).

The European Financial Information Sharing and Analysis Centre (EU-FI-ISAC) functions as a platform for the exchange of information between financial institutions operating within the European Union. European FI-ISAC is an independent organization supported by ENISA (European Union Agency for Cybersecurity). FI-ISAC's mission is to exchange information on electronic and mobile channels, cards, central systems, and all ICT-related issues, including (European FI-ISAC):

- cybercrime affecting the financial community,
- vulnerabilities, technology trends, and threats,
- incidents, and case studies.

The European Cybercrime Center (EC3) was established by Europol to strengthen law enforcement efforts in combating cybercrime, thereby protecting European citizens, businesses, and governments from online crime. Since its establishment in 2013, EC3 has contributed significantly to the fight against cybercrime and has participated in numerous high-profile operations (EUROPOL Cybercrime Centre).

The Basel Committee on Banking Supervision (BCBS) is the body that sets global standards for prudential regulation of the banking sector and provides a forum for regular cooperation on supervisory matters. Its 45 members are central banks and banking supervisory authorities from 28 jurisdictions. The BCBS's main objective is to enhance the stability and resilience of the global financial system and to ensure that no bank can escape supervision by operating solely within the borders of a single country (The Basel Committee).

The European Union Agency for Cybersecurity (ENISA) is responsible for ensuring a high and effective level of security in networks and information systems in the European Union. ENISA's task is to ensure a uniform level of cybersecurity across Europe. ENISA participates in the implementation of EU policy in the field of cybersecurity. It builds trust in digital products and services by designing cybersecurity certification systems (Enisa).

Cooperation between banks in the Polish banking sector manifests itself in various types/forms of coopetition, examples of which are as follows:

- Network-based.
- Formal.
- Informal.
- Indirect.
- Direct.

The sectoral threat information sharing centers (FS-ISAC) that have been established can be regarded as a model of formal network coopetition. Banks that are members of FS-ISAC anonymously share data on incidents, indicators of compromise (IOCs), and best practices in near real time. Another example is joint cyberattack simulation platforms, where teams from competing banks jointly train to respond to a coordinated attack on critical infrastructure. Informal coopetition can be ad hoc and based on telephone/email alerts about a newly observed threat, or meetings where valuable insights are exchanged.

In indirect coopetition, the regulator (e.g., the Financial Supervision Authority, the European Banking Authority, or national authorities) acts as a catalyst and oversees cooperation. The regulator not only imposes legal obligations on banks in the area of cybersecurity (NIS2 directive, EBA standards), but also often creates platforms for the exchange of information. Direct coopetition is a grassroots initiative by banks themselves, undertaken without direct regulatory coercion. It stems from purely business-based risk calculations. Banks themselves decide on bilateral or multilateral data exchange, joint purchases of security services from external providers, or the creation of common industry standards that go beyond minimum legal requirements. No single model of coopetition is optimal in all situations. An effective defense ecosystem requires their parallel use. Regulator-supervised coopetition is essential to ensure a basic, uniform level of security across the sector. Direct and informal coopetition is the driving force behind advanced, innovative forms of cooperation, allowing for immediate response once a threat has been identified.

4. Results

In order to obtain answers to the research questions, interviews were first conducted with representatives of seven banks operating in Poland to establish the research criteria, and then responses to previously prepared research questionnaires were obtained from the employees of these banks. The respondents were 107 people working in departments dealing with fraud prevention, cybersecurity, compliance, and IT security engineering. The survey used a 5-point Likert scale with the following options: 1 – Completely irrelevant (CR), 2 – Not very relevant (NR), 3 – Neutral (N), 4 – Relevant (R), 5 – Very relevant (VR). Table 1 presents the reasons for banks to cooperate in the area of cybersecurity.

Cyber threats are perceived as the most important drivers of coopetition, while regulatory pressure is also very important, but to a slightly lesser extent. During the interviews, it was established that respondents perceived the following issues, among others, as other reasons: reduction of operating costs, joint investments in technology development, and response to changing customer expectations.

Table 1.*Causes for cooperation in the Polish banking sector*

Causes	AM	SD	CR	NR	N	R	VR
Cyberattacks on the banking sector	4.63	0.59	0%	2%	3%	29%	67%
EU legal regulations	4.53	0.80	2%	2%	3%	28%	65%
Overall growth in cyberattacks	4.46	0.91	3%	3%	4%	27%	63%
National legal regulations	3.84	1.21	4%	13%	20%	22%	41%
Pressure from fintech companies	3.71	1.24	8%	8%	22%	28%	34%
Other	3.17	1.09	10%	23%	26%	36%	5%

AM – Arithmetic Mean, SD – Standard deviation, CR – Completely irrelevant, NR – Not very relevant, N – Neutral, R – Relevant, VR – Very relevant.

Source: Own work based on a survey questionnaire.

Undoubtedly, the most important reasons for cooperation between banks are cyber threats, especially those directed specifically at the banking sector. Average ratings indicate a very high, shared perception of risk. EU regulations are seen as a significantly stronger incentive than national regulations. Directives such as PSD2, which enforce data sharing, themselves create the groundwork for coopetition. Pressure from fintechs is proving to be a significant, though not the most important, factor influencing the adoption of coopetition.

Table 2 presents the survey results in the context of answering the question of which cyberattacks pose the greatest threat to the banking sector. The survey used a 5-point Likert scale with the following options: 1 – Very low (VL), 2 – Low (L), 3 – Medium (M), 4 – High (H), 5 – Very high (VH). Phishing, APT, and ransomware are the most serious threats, as evidenced by the highest averages (above 4.4). The low standard deviation for phishing and APT indicates that respondents agree on the severity of these attacks. Attacks on SWIFT are also rated as very high risk, reflecting the strategic importance of this system.

Table 2.*The degree of threat posed by the indicated types of cyberattacks to the banking sector*

Cyberattacks types	AM	SD	VL	L	M	H	VH
Phishing	4.65	0.69	0%	2%	6%	16%	76%
Advanced Persistent Threats (APTs)	4.52	0.78	0%	3%	9%	21%	67%
Ransomware	4.43	0.86	0%	4%	13%	20%	63%
Attacks on SWIFT	4.15	1.11	2%	10%	13%	21%	54%
DDoS	3.92	1.29	5%	14%	17%	14%	54%
Attacks on cloud computing	3.75	1.17	7%	12%	8%	46%	27%
Man in the Browser	3.64	1.22	5%	20%	11%	35%	29%
Digital skimming	3.22	1.26	9%	22%	27%	21%	21%
Living off the Land (LOTL)	3.05	1.17	7%	29%	29%	21%	14%
Other	2.45	1.07	21%	32%	30%	14%	3%

AM – Arithmetic Mean, SD – Standard deviation, VL – Very low, L – Low, M – Medium, H – High, VH – Very High.

Source: Own work based on a survey questionnaire.

Figure 1 shows the distribution of responses regarding the threat of phishing (average = 4.65). Banks and financial institutions store vast amounts of customer personal data (social security numbers, account numbers, identification data) and manage large financial flows. This makes them a very attractive target for criminals. Phishing is primarily an attack on

people, through emails, text messages, and impersonating a trusted institution. As bank employees or their customers can be a vector of entry, phishing poses a very high threat, as illustrated by the chart.

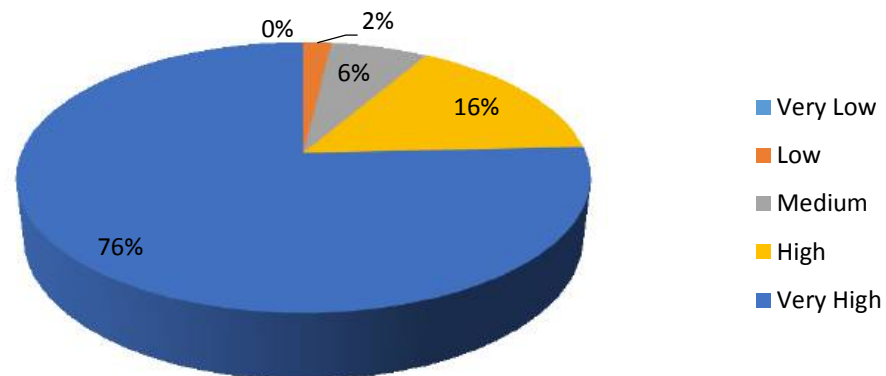


Figure 1. Distribution of responses to a phishing cyberattack.

Source: Own work based on a survey questionnaire.

Table 3 presents the survey results in the context of answers to the question of which effects of cyberattacks are most serious for banks/the banking sector. The survey used a 5-point Likert scale with the following options: 1 – Very low (VL), 2 – Low (L), 3 – Medium (M), 4 – Serious (S), 5 – Critical (C). The most serious threats in the respondents' perception are those that destroy the bank's intangible assets, i.e., customer trust (average 4.74) and reputation, and lead to direct financial and legal consequences (losses, penalties). The results show that modern banks fear not only cyberattacks themselves, but above all their cascading business, legal, and reputational consequences.

Table 3.

The degree of significance of the effects of cyberattacks on the banking sector

Type of cyberattacks impact	AM	SD	VL	L	M	S	C
Loss of customer trust	4.74	0.56	0%	0%	6%	15%	79%
Data leaks	4.62	0.61	0%	0%	7%	25%	68%
Regulatory penalties and fines	4.52	0.78	0%	2%	12%	18%	68%
Financial losses	4.41	0.93	0%	7%	8%	20%	64%
System disruptions	4.34	0.99	0%	9%	9%	20%	62%
Loss of trust in the banking sector	4.10	0.88	0%	7%	14%	42%	37%
Discrediting of trading platforms	4.01	0.79	0%	6%	14%	54%	26%
Bank employee involvement in cyberattacks	3.57	0.74	1%	6%	36%	51%	7%
Acquisition of know-how by perpetrators	3.48	0.71	3%	2%	42%	51%	2%
Other	2.68	0.69	3%	36%	50%	10%	0%

AM – Arithmetic Mean, SD – Standard deviation, VL – Very low, L – Low, M – Medium, S – Serious, C – Critical.

Source: Own work based on a survey questionnaire.

Table 4 presents the results of the survey in the context of answering the question of what benefits may result from co-opetition between banks in response to cyberattacks. The survey used a 5-point Likert scale, with the following options: 1 – No benefit (NB), 2 – Minor benefit (MnB), 3 – Moderate benefit (MdB), 4 – Major benefit (MjB), 5 – Very major benefit (VMB). By sharing data on new attack vectors or detected incidents, banks can respond much more

quickly to emerging risks. This prevents a single attack from escalating into a mass attack affecting multiple institutions simultaneously. Cooperation enables the creation of consistent and up-to-date standards for technical solutions, security policies, identity management, and incident response processes. Standardization raises the average level of protection in the industry. When every institution has access to the most up-to-date threat data and applies best practices, consumers gain a truly safer environment for using financial services. The risk of identity theft or loss of funds is also reduced. Shared analytical systems and the exchange of warning signals allow for faster identification of unusual events and counteraction to their effects.

Table 4.

The benefits of coopetition among banks in the context of cybersecurity

Benefits	AM	SD	NB	MnB	MdB	MjB	VMB
Faster exchange of information about threats	4.61	0.79	0%	4%	7%	13%	76%
Joint development of standards	4.44	0.87	0%	5%	11%	20%	64%
Increased customer protection	4.33	0.93	0%	5%	18%	18%	60%
More efficient detection of anomalies	4.21	0.95	0%	11%	3%	40%	46%
Limiting the impact of cyberattacks	4.12	1.00	0%	11%	10%	34%	45%
Reducing serious incidents	4.02	1.04	0%	13%	13%	33%	41%
Joint incident simulations	3.85	1.07	2%	16%	7%	47%	29%
Increasing operational resilience	3.70	1.06	3%	10%	27%	34%	26%
Technological improvement	3.53	1.01	3%	12%	32%	36%	18%
Cost reduction	3.47	0.96	5%	8%	34%	42%	11%
Increasing the costs for cybercriminals	3.43	0.93	5%	9%	32%	47%	7%
Regulatory lobbying	3.37	0.86	4%	11%	32%	50%	3%
Other	3.04	0.78	7%	8%	60%	25%	0%

AM – Arithmetic Mean, SD – Standard deviation, NB – No benefit, MnB – Minor benefit, MdB – Moderate benefit, MjB – Major benefit, VMB – Very major benefit.

Source: Own work based on a survey questionnaire.

The survey clearly shows that the banking sector sees very specific, tactical benefits from coopetition in the area of cybersecurity. The most highly valued activities are those that directly translate into rapid response times and common standards. Cost and political (lobbying) aspects are considered important, but less crucial for direct defense against cyberattacks. Figure 2 illustrates the distribution of responses for the most highly rated benefit (average = 4.61) resulting from bank coopetition. While joint initiatives obviously allow for cost reductions through economies of scale, and a coordinated industry voice has greater leverage with regulators, operational effectiveness remains the priority in the context of immediate threats. In the face of increasingly sophisticated cybercriminals, a common line of defense is proving to be a necessity, not just an option.

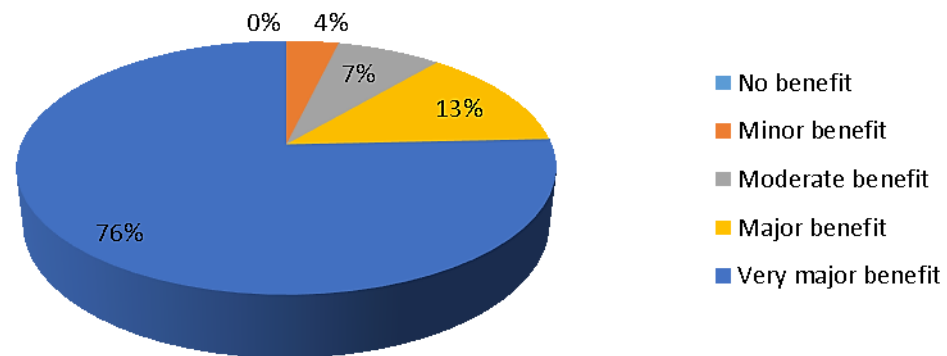


Figure 2. Distribution of responses for the benefit of faster information exchange.

Source: Own work based on a survey questionnaire.

Table 5 presents the results of the survey in the context of answering the question of what barriers may arise from co-opetition between banks in response to cyberattacks. The survey used a 5-point Likert scale, with the following options: 1 – Completely irrelevant (CR), 2 – Not very relevant (NR), 3 – Neutral (N), 4 – Relevant (R), 5 – Very relevant (VR).

Table 5.
Barriers to cooperation in the Polish banking sector

Barriers	AM	SD	CR	NR	N	R	VR
Risk of confidential data leaks	4.67	0.79	0%	4%	7%	13%	76%
Lack of trust in other banks	4.54	0.87	0%	5%	11%	20%	64%
Fear of losing competitive advantage	4.25	0.93	0%	5%	18%	18%	60%
Legal and compliance issues (GDPR)	4.12	0.95	0%	11%	3%	40%	46%
Different levels of security maturity	4.07	1.00	0%	11%	10%	34%	45%
Risk of intellectual property theft	3.91	1.04	0%	13%	13%	33%	41%
Coordination costs	3.44	1.07	2%	16%	7%	47%	29%
Technical complexity of integration	3.22	1.06	3%	10%	27%	34%	26%
Culture of competition between banks	3.11	1.01	3%	12%	32%	36%	18%
Other	2.88	0.96	5%	8%	34%	42%	11%

AM – Arithmetic Mean, SD – Standard deviation, CR – Completely irrelevant, NR – Not very relevant, N – Neutral, R – Relevant, VR – Very relevant.

Source: Own work based on a survey questionnaire.

The two key barriers are the risk of confidential data leaks (average = 4.67) and lack of trust in other banks (average = 4.54). These are clearly more important than the others. For coopetition to be possible, it is necessary to develop extraordinary mechanisms for data protection and confidentiality, and to build trust. Another set of barriers is related to competitiveness: fear of losing advantage and the risk of intellectual property being taken over, which are linked to limited trust in competitors. Legal issues (GDPR) and varying levels of security maturity are seen as important, but not as crippling as issues of mutual trust. This points to areas where the development of standards and models of cooperation could bring quick benefits. Respondents also pointed to the technical complexity of integration and the culture of competition as significant obstacles. This confirms the assumption that, apart from technology, the human and cultural aspects may prove to be the greatest challenge in relation to the coopetition of banks.

5. Discussion

The present study provides empirical and theoretical evidence that coopetition among banks is not only a viable but increasingly necessary strategy in responding to the growing cyber-risk landscape. The findings corroborate and extend prior scholarship on financial-sector cooperation, regulatory influence, and cyber resilience.

5.1. The strategic role of coopetition in cyber-resilience

The survey reveals, that cyberattacks, particularly phishing, APTs, and ransomware, are perceived by banking-sector professionals as the most significant drivers of cooperative behavior (Tables 1-2). This aligns with the conceptualization of cyber risk as a systemic threat: not merely an operational issue, but one that can cascade across institutions. Recent work has framed cyber risk in banks as a form of systemic risk, due to interconnections and shared infrastructures (Birindelli, Iannuzzi, 2024). By cooperating, especially via threat-intelligence sharing, banks effectively internalize some of the externalities associated with cyber risk, benefiting from collective vigilance.

Moreover, the finding, that threat intelligence exchange is the top-rated benefit (mean = 4.61) underscores the strategic value of Information Sharing and Analysis Centers (ISACs). This is consistent with literature on CTI (cyber threat intelligence) ecosystems: sharing platforms foster knowledge advantages by improving detection and response capabilities across participants (Abraham et al., 2025). For instance, Sayeed et al. (2024) argue, that resource sharing, underpinned by institutional and protection motivation theories, strengthens long-term security outcomes in the financial sector.

5.2. Regulatory drivers and constraints

Regulatory incentives emerged strongly in our data: EU regulation (e.g., DORA, NIS2) scores nearly as high as cyber-risk itself. The importance of regulation in fostering coopetition echoes findings from the U.S. financial sector: Atkins and Lawson (2021) show that regulatory pressure and trust networks have been key in enabling public-private cyber collaboration. However, legal and compliance barriers, particularly concerns about GDPR and banking secrecy, remain major obstacles (Table 5). This tension between cooperation and confidentiality reflects broader challenges in coopetition theory: competing firms must balance mutual dependence with competitive safeguards. The literature on coopetition management highlights precisely these relational tensions (asymmetry, trust, paradoxicality) as critical features to operationalize (Tagscherer, Carbon, 2024). In the context, the design of intelligence-sharing frameworks must therefore emphasize strict data governance (e.g., anonymization, metadata-only sharing) and legal safeguards to maintain confidentiality while enabling collaboration.

5.3. Trust, culture and institutional maturity

Respondents identified lack of trust and the risk of confidential data leaks as among the most significant barriers, more so than technical integration or coordination costs. This underscores, that coopetition is not merely a technological problem, but fundamentally a social and organizational one. The success of CTI ecosystems therefore depends on trust-building mechanisms, reputation, and institutional maturity.

This finding echoes broader financial-sector coopetition scholarship: Marecki and Wójcik-Czerniawska (2023) discuss, how coopetition among banks and non-bank entities is shaped by mutual dependence and regulatory architecture. To build trust, banks may need to formalize cooperative structures (e.g., via sectoral ISACs or joint simulation exercises) rather than rely solely on informal ad hoc arrangements.

6. Summary

This article aimed to analyze the phenomenon of coopetition in the Polish banking sector as a response to cyber threats and legal regulations. The research confirmed the research hypothesis, indicating that cyberattacks and related legal regulations are key catalysts for cooperative activities among banks. In response to the research questions, it was determined that the most serious types of cyberattacks prompting coopetition include phishing, advanced persistent threats (APTs), ransomware, attacks on the SWIFT system, and DDoS attacks. An analysis of the effects of these attacks showed that the sector's greatest concerns are loss of customer trust, data leaks, and regulatory penalties, which directly motivate joint action.

When it comes to legal regulations, research shows that EU legislation (average: 4.53) is primarily perceived as the main driver of coopetition. At the same time, at the national level, problems with the interpretation and application of the GDPR have been identified as a significant legal barrier hindering the free exchange of information on threats. Clear benefits and barriers to coopetition have also been identified. The most important benefits include faster exchange of information on threats, joint development of security standards, and increased customer protection. The main barriers, on the other hand, are the fear of confidential data leaks, lack of trust between banks, and fear of losing competitive advantage.

In summary, the Polish banking sector recognizes both the urgent need for and the tangible benefits of cooperation in the area of cybersecurity. Nevertheless, the success of cooperative initiatives depends on overcoming deeply rooted barriers of trust and competition, while adapting the legal framework to support rather than hinder such cooperation. In light of the results obtained, further research in this area could focus on the following areas:

- Research as part of a comparative analysis of the effectiveness of existing coopetitive structures in the banking sectors of other countries in order to develop best practices for Poland.
- Detailed analysis of the impact of individual legal acts (e.g., NIS2, DORA directives) on the dynamics of competitive cooperation, taking into account implementation costs and long-term effects.
- Monitoring how the emergence of new types of cyber threats (e.g., related to artificial intelligence or quantum technology) affects banks' readiness for deeper cooperation.

When applying the phased model of coopetition implementation in the field of cybersecurity, it is worth considering three implementation stages. Phase 1: Foundational trust-building and limited information sharing (Short-Term: 0-12 months). Objective: Establish basic cooperation protocols and build initial trust through low-risk, high-impact activities. Key activities/actions:

- Structured metadata exchange: Implement a standardized format for sharing anonymized, technical Indicators of Compromise (IOCs), such as malicious IP addresses, file hashes, and domain names, through the existing ZBP FinCERT.pl platform. This minimizes legal and data privacy risks.
- Joint threat landscape analysis: Conduct regular, facilitated workshops where banks can discuss general threat trends and attack methodologies without disclosing sensitive internal data.
- Development of a common governance framework: Create a clear charter for cooperation, defining roles, responsibilities, data handling procedures, and rules of engagement to address fears of losing competitive advantage.

Phase 2: Standardization and operational collaboration (Medium-term: 12-24 months). Objective: Deepen cooperation by aligning technical and procedural standards and initiating joint operational exercises. Key activities/actions:

- Gradual standardization: Jointly develop and adopt common technical standards for security controls, incident response playbooks, and data anonymization techniques, building on the initial exchange protocols from Phase 1.
- Periodic joint table-top simulations: Organize regular, scenario-based exercises simulating coordinated cyberattacks (e.g., on the SWIFT system or critical national infrastructure). These simulations train joint response capabilities and strengthen interpersonal trust among security teams.
- Establishment of a shared knowledge base: create a centralized, secure repository for best practices, vulnerability assessments, and non-attributable incident reports, accessible to all participating banks.

Phase 3: Advanced integration and proactive defense (Long-term: 24+ months). Objective: Achieve a mature coopetition ecosystem capable of proactive, collective defense. Key activities/actions:

- Collaborative threat hunting: Form joint analyst teams to proactively hunt for threats across participating banks' ecosystems, leveraging shared intelligence and analytics.
- Joint investment in advanced technologies: Explore consortium-based purchasing or co-development of advanced cybersecurity solutions, such as shared Security Operations Center (SOC) capabilities or AI-powered threat detection platforms, to reduce costs and increase capability.
- Unified regulatory engagement: Present a coordinated, sector-wide position to regulators (KNF, UOKiK) and legislators on cybersecurity policy, leveraging the collective experience from Phases 1 and 2 to shape a more supportive legal environment.

In conclusion, the Polish banking sector recognizes both the urgent necessity and the tangible advantages of coopetition in bolstering its cyber resilience. The benefits, ranging from accelerated threat intelligence sharing and the joint development of security standards to enhanced customer protection, are clearly perceived as vital for navigating the contemporary threat landscape. Nevertheless, the full potential of this strategic approach remains contingent upon the sector's ability to overcome deeply ingrained barriers of trust and competition.

This requires not only internal cultural shifts but also an adaptive legal framework that can support secure information sharing without compromising confidentiality or compliance. For future research, a comparative analysis of coopetitive models in other national banking sectors, a detailed investigation into the implementation dynamics of specific regulations like NIS2 and DORA, and ongoing monitoring of how emerging technologies such as AI and quantum computing reshape the threat landscape and, consequently, the impetus for cooperation, are identified as promising avenues to further develop best practices and theoretical understanding.

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SLOWMADISM AS AN EVOLUTIONARY FORM OF DIGITAL NOMADISM. IMPLICATIONS FOR MANAGING THE DEVELOPMENT OF TERRITORIAL UNITS

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Purpose: This article aims to present the phenomenon of slowmadism and the results of empirical research related to identifying city characteristics that influence decisions to stay longer in a destination. The paper sheds light on a better understanding of the evolving form of digital nomadism, which involves longer stays and better integration into the city's local culture.

Design/methodology/approach: A qualitative study was conducted using semi-structured interviews. Twenty digital nomads participated in the study, all of whom had stayed in a single destination for more than three months at least once during their nomadic lifestyle. All digital nomads participated in the study remotely, via social media messaging.

Findings: Nearly every second respondent highlighted the importance of friendly locals and a welcoming local community, which enabled them to build relationships and feel a sense of belonging. Economic factors such as affordable prices and accessibility were equally frequently cited. Social and economic aspects are the most important determinants of longer stays among the surveyed digital nomads. Furthermore, digital nomads choose Asia as the main continent for more extended stays. More than half of the respondents declared that their longest stay was in an Asian city.

Research limitations/implications: The most significant limitation of the study is the remote nature of the interviews, which could have influenced both the process of interpretation of the obtained data by the researcher and the level of authenticity and credibility of the respondents' statements.

Practical implications: City authorities seeking to attract digital nomads for more extended stays should use their marketing efforts to shape the image of a space with reasonable living costs, that is open, and culturally friendly. At the same time, it is crucial to strengthen the local identity and culture, which form the foundation of a city's unique and authentic image.

Originality/value: The research findings enhance the understanding of why digital nomads choose to extend their stay in a destination, an aspect that has been insufficiently explored empirically.

Keywords: slowmadism, digital nomadism, digital nomads, nomads destinations.

Category of the paper: Research paper.

1. Introduction

Digital nomadism has quickly transformed from a niche phenomenon into a global trend. Currently, there are approximately 40 million digital nomads worldwide, with this number steadily increasing (Kumar, 2025). Although the concept of combining remote work with travel emerged in the late 1990s (Makimoto, Manners, 1997), it is only since 2020 that this phenomenon has seen dynamic growth among both nomads and the academic community (Cook, 2023). In recent years, researchers have increasingly attempted to analyze digital nomadism from an interdisciplinary perspective. The scientific community is focusing on the impact of this trend on local economies, urban communities, and the behavioral patterns of remote mobile workers.

A relatively new and under-explored concept in the scientific literature is "slowmadism", which refers to the concept of nomadism, considered an evolutionary form of digital nomadism (Baptista, 2024). Although digital nomads, by definition, prefer longer stays in a given location than tourists and typically spend one to three months in one place, recent research indicates that some of them consciously choose a more extended stay in one destination, thus distinguishing themselves from the more mobile representatives of this group (Sztuk, 2025).

The phenomenon of slowmadism has not yet been directly empirically studied. Therefore, the goal of this article is to identify the city characteristics that influence digital nomads' decisions to stay in a given location beyond the generally accepted three-month period. To this end, a qualitative study was conducted based on semi-structured individual interviews with digital nomads who had decided to extend their stays in selected destinations. The obtained results allow for a better understanding of the motivations of this group and identify factors contributing to the development of slowmadism.

2. Theoretical background: digital nomadism and slowmadism

Digital nomadism is a contemporary lifestyle that involves performing professional duties remotely from any chosen location worldwide (Wang et al., 2018). A characteristic feature of this model is frequent relocation, typically every one to three months (Tagliaferri, 2023). Definitions of digital nomadism emphasize high mobility and combining work with travel. The concept of digital nomadism assumes a shift from a traditional lifestyle to one of frequent relocation and the absence of a fixed location.

Digital nomads leverage digital technologies to work remotely, allowing them to complete their tasks from anywhere. They are known for their strong self-discipline and a desire for independence in selecting their work locations (Cook, 2020, 2023). For digital nomads,

the choice of destination is vital, as it significantly affects their work comfort and the overall quality of daily life (Ehn, Jorge, Marques-Pita, 2022).

With the rapid growth in the number of digital nomads, many destinations have begun to modify their marketing strategies in an effort to attract mobile, remote workers (Hannonen, 2020). Cities' interest in attracting digital nomads stems from their potential to promote a positive image of a place, which is an important, intangible resource influencing the attractiveness of territorial units (Gosik, Żelazna-Jochim, 2018). Digital nomads share their experiences on social media and run travel blogs, documenting their daily lives and impressions of the places they visit (Bonneau, Aroles, 2021; Sztuk, 2023). In this way, they contribute to the dissemination of the city's image and strengthen its recognition.

In the literature, digital nomads are described both as a new target group for urban offerings (Sztuk, 2023) and as a new segment of the workforce with specific characteristics in the contemporary labor market (Ersöz, 2024). Their number is expected to continue to grow, not only due to their attractive lifestyle (Kumar, 2025) but also as a result of the ongoing digital transformation of enterprises (Johnson, 2022).

Given that the average stay of a digital nomad in a given destination typically lasts from several to a dozen or so weeks, the slowmadism phenomenon begins around the fourth month of uninterrupted stay in one place. Slowmadism is currently considered a new form of digital nomadism and, at the same time, a distinctive lifestyle (Baptista, 2024). It represents a slower variant of digital worker mobility, enabling them to understand the local culture better, integrate with the community, and establish relationships within social and professional groups.

Practicing slowmadism promotes not only productivity but also social well-being through the opportunity to build relationships and immerse oneself in the everyday life of one's location (Basu, 2024). Compared to traditional digital nomadism, slowmadism allows for a deeper understanding of the cultural and social context of a given territorial unit and an authentic experience of the local rhythm of life (Poulaki et al., 2023). Longer stays also foster the development of one's routine and emotional stability, which can be limited in the classic model of frequent relocation. Despite its numerous advantages, the digital nomad lifestyle presents significant challenges, such as the lack of a permanent home base, the frequent need to adapt to a new environment, and the difficulty of maintaining a regular daily routine (Sztuk, 2025). In this context, slowmadism represents an adaptive form of living that mitigates the adverse effects of excessive mobility.

From an environmental perspective, it is also important that the reduced frequency of travel in the slowmadism model may contribute to reducing the carbon footprint generated by frequent travel (Poulaki et al., 2023). The newly distinguished mobility category of slowmadism indicates that digital nomadism is not homogeneous. However, it encompasses the entire spectrum of forms and intensity of travel combined with remote work (Reichenberger, 2018).

When analyzing the concept of slowmadism in the context of scientific literature, it is worth relating it to the concept of slow tourism. Slow tourism is an alternative model of travel, the opposite of mass tourism (Serdane, Maccarrone-Eaglen, Sharifi, 2020). Its essence is exploring the authenticity of a place, local culture, and identity, and visiting less popular areas and attractions (Valls et al., 2019). Slow tourism allows for a focus on the qualitative, rather than quantitative, aspects of travel. Trips are undertaken less frequently but last longer and are more reflective. This trend, as indicated, is continuing to grow (Balaban, Keller, 2024).

While slowmadism and slow tourism share common assumptions based on the idea of a mindful, authentic experience of space, they differ in the functional purpose of their stay. Those practicing slow tourism do not combine travel with work and return to their permanent residence after their vacation. Digital slow nomads, on the other hand, continue their professional activities remotely during extended stays, and after leaving one location, they move to another destination, maintaining a mobile lifestyle.

3. Methods

To identify city characteristics that influence digital nomads' decisions to stay in a given location beyond the generally accepted three-month period, a qualitative approach was used (Creswell, 2013). A semi-structured interview method allows participants to be asked the same questions while also facilitating deeper responses through the use of clarifying questions (Kvale, 2010). In qualitative research, the research sample does not have to meet the requirements of statistical representativeness. Researchers indicate that the minimum number of respondents participating in interviews should be at least 10 or 15 (Atran, Medin, Ross, 2005, p. 753; Mason, 2010, p. 13).

Respondents were recruited through social media platforms, Instagram and Facebook. Digital nomads were invited to participate in the study, which included information about its purpose and nature. The invitation was sent to approximately 100 potential participants. The response rate was approximately 35%. Of those who expressed interest in participating, 13 digital nomads were ultimately excluded from the sample, as their maximum length of stay in a single city was two to three months. Ultimately, 20 digital nomads who had spent more than three months in a given destination participated in the study, which was considered the lower limit for qualifying as slowmadism. Each participant was asked questions about the characteristics of the location that led them to an extended stay. Twenty respondents participated in the study, including 14 men and 6 women, one of whom was a couple traveling together on the same nomadic trip. Additionally, 2 participants indicated more than one place where they stayed for a period exceeding three months during a single travel cycle.

According to the methodology of conducting research interviews, the criterion for terminating the research process is achieving theoretical saturation (Konecki, 2000). Data saturation occurs when new data collection begins and further interviews fail to yield significant new information (Okólska, 2020). In the case of this study, conducted among digital nomads, theoretical saturation was reached after the twentieth interview, at which point the respondent strongly emphasized the importance of the community.

During the analysis of the collected research material, the complex statements made by digital nomads were first condensed into shorter sentences that conveyed the entire meaning of the message. Next, keywords were extracted from each statement, which referred to the characteristics of the place, thereby indicating its unique features. Ultimately, this allowed us to identify the most frequently occurring characteristics of destinations for extended stays by digital nomads. A total of 9 location characteristics were identified, which occurred at least twice and were found to be determinants of extended stays in a given location. These characteristics were then assigned to specific categories, creating 3 factors: economic, environmental, and social/cultural. The study was conducted in the fall of 2025. All respondents were actively leading a nomadic lifestyle at the time of participation, i.e., working remotely while traveling.

4. Results

Among the twenty digital nomads surveyed, each respondent described the city in which they chose to spend an extended stay (Table 1). Analysis of their responses indicates that for the vast majority of participants (18), this was the only place where they stayed for longer than 3 months during leading a mobile, nomadic lifestyle. 2 individuals declared that they had stayed in the city for more than three months at least twice.

In-depth interviews revealed that the typical stay of digital nomads in a single location is relatively short (1-3 months), and extended stays are usually exceptional. The longest recorded case involved respondent 12, who spent 5 years in one country, traveling between cities and villages in the Lubuskie Voivodeship, spending most of that time in Zielona Góra. This was the longest trip recorded. The shortest extended stay, however, was 4 months. In one case, this involved someone who was still in a given city at the time of the study and was considering extending their stay. Respondents' statements indicate that staying in one place for an extended period was often associated with positive emotions and a sense of belonging due to the city's energy. Digital nomads described these locations as spaces conducive to slowmadism, a lifestyle combining mobility with longer, more reflective stays. Most such trips ranged from 4 to 8 months.

Table 1.*Cities and reasons visited by digital nomads in slow mode*

	Sex	City	Why - features of the place **	Time
1	M*	Siem Reap	There are no crowds in popular spots for digital nomads. Most people are retired. There are good restaurants, friendly locals, The river is within walking distance, and there are plenty of cafes.	12 months
2	F*	Chiang Mai	Culture, northern Thai food, nice community, everything you need if you need it, healthcare, visas for digital nomads.	11 months
3	M	Hanoi	The food is good, life is peaceful, I enjoy the nightlife, and I've made many good friends here. The climate can be unfavorable, but you can avoid the cold by moving to the other side of Vietnam.	3 years breaks for other trips
4	M	Chiang Mai	Cheap, convenient, fun, lots of places to discover	4 months
5	M	Da nang	I felt very productive here thanks to the beaches and the suitable coworking conditions and atmosphere of the place.	12 months
6	M	Varna	I keep going back there, it's a really good, cheap place to stay.	13 months
7	M	Hanoi	It wasn't a perfect place, but it met all my goals in life at the time: the ability to work remotely, good prices, and an atmosphere.	36 months
8	M	Montevideo	The city has everything I need, and the time zone is between the USA and Europe, very nice and friendly people.	10 months
9	F	Tibilisji	Good prices and short-term rental options compared to other places, mild winters.	6 months
10	C*	Tirana	We fell in love with this country and its culture, its also affordable.	7 months
11	M	Bali	This place is economic, fun, relaxing and safe place.	4 months
12	M	Lubuskie v.	Whole region has delicious food, low prices and is very safe.	5 years
13	M	Bali	Legally, it is friendly to digital nomads, has a great culture and friendly people, and is also a cheap place to stay with delicious food and great weather.	4 months
14	F	Bali Meksyk	I chose both places because of the easy visa procedures. Later, I discovered a community I didn't want to leave.	6 months 10 months
15	M	Sydney	I've found the perfect work-life balance here. The pay is very good, so it's worth saving for future travel.	11 months
16	M	Madryt	History, architecture, I can teach English here in the meantime, there are many students willing.	24 months
17	M	Asuncion	I love this place, the strong economy, the wonderful people, and the incredible tax benefits. In South America, a digital nomad's stay can be extended to up to six months. I can live here for 1500 euros, which is very favorable price.	4 months with extension possibility
18	M	Bangkok	Warm climate, nice people, very polite and sweet, lgbt friendly, Bangkok is big and has literally everything.	8 months
19	F	Kuala Lumpur	I was able to learn and do many new things, like attending Latin American nights, expat meetups, and film groups, which allowed me to truly connect with people over the long term. It's all about connecting and building connections with people.	12 months
		Belgrad	There are certain characteristics I consider when choosing a city: affordability, community, and excellent digital infrastructure. Here I learned to dance tango in Belgrade, which meant attending the same school and meeting friends and a small dance community there.	4 months
20	F	Rome	My length of stay depends on how I feel in a given city. The longer stay, however, stemmed from me trying to stay long enough to truly experience the local culture and energy, which was wonderful.	8 months

*M: male, F: female, C: couple. ** Nomads' statements reduced to the essentials.

Source: own elaboration based on research.

Digital nomads' responses regarding their reasons for staying longer in a given destination were coded. Respondents' complex narratives were first reduced to simple sentences and then to keywords representing specific features and attributes of the destination (table 2).

Table 2.*The most frequently mentioned city features by digital nomads*

	Feature	Occurrences
1.	Affordable prices	9
2.	Friendly people/hospitable local community	9
3.	Local culture and atmosphere of the place	5
4.	Good food	4
5.	Working conditions /digital infrastructure	4
7.	Simple visa procedures	3
8.	Development/learning opportunities/additional activities	3
9.	Safety	2

Source: own elaboration based on research.

The analysis revealed that nearly every second respondent (9 nomads) emphasized the importance of friendly locals and a welcoming local community, which enabled building relationships and a sense of belonging. Economic factors, such as affordable prices and a favorable cost-to-quality ratio, were equally frequently cited. This can be defined as the overall economic accessibility of a given location. These two groups of social and economic factors are the most important determinants of a longer stay among the digital nomads surveyed. 5 interviews included references to the city's culture and atmosphere, which are significant factors in attracting and extending their stay. Good regional cuisine and suitable working conditions, including developed digital infrastructure and the availability of coworking spaces, were also important factors for 20% of respondents. 3 respondents also cited favorable visa regulations for digital nomads and a sense of productivity and opportunities for personal development in the location. 2 respondents, however, emphasized the importance of security as a prerequisite for extending their stay in a given location.

In relation to the locations where the surveyed digital nomads decided to stay longer in the slowmadism mode, their geographical distribution was analyzed, covering both the country and the continent (Table 3).

Table 3.*Cities visited by digital nomads in slow mode*

Continent	Country	City/location	Number of indications	Percentage of the total
Asia	1. Thailand	Chiang Mai (2), Bangkok	3	54,5%
	2. Indonesia	Bali	3	
	3. Vietnam	Hanoi (2), Da Nang	3	
	4. Georgia	Tbilisi	1	
	5. Cambodia	Siem Reap	1	
	6. Malaysia	Kuala Lumpur	1	
Europe	1. Albania	Tirana	1	27,3%
	2. Poland	Zielona Góra/Lubelskie v.	1	
	3. Spain	Madrid	1	
	4. Bulgaria	Varna	1	
	5. Serbia	Belgrade	1	
	6. Italy	Rome	1	

Cont. table 3.

South America	1. Uruguay	Montevideo	1	9,1%
	2. Paraguay	Asuncion	1	
North America	1. Mexico	Mexico City	1	4,5%
Australia	2. Australia	Sydney	1	4,5%

Source: own elaboration based on research.

The results indicate that digital nomads choose Asia as the main continent for more extended stays. Over half of the respondents declared that their longest stay was in an Asian city. Thailand, Indonesia, and Vietnam were among the most frequently mentioned countries, confirming the continued attractiveness of the Southeast Asian region for this group of mobile workers. Bali was the most popular destination (3 responses), followed by Chiang Mai, Thailand (2 responses), and Hanoi, Vietnam (2 responses).

The second most frequently chosen region was Europe, selected by 6 respondents. Unlike Asia, there were no duplicates of the same countries, which may indicate greater diversity of choices within the European continent.

Based on interviews with digital nomads, three main factors influencing the decision to extend their stay in a given location, beyond the typical mobility period of this group, were identified (Fig. 1).

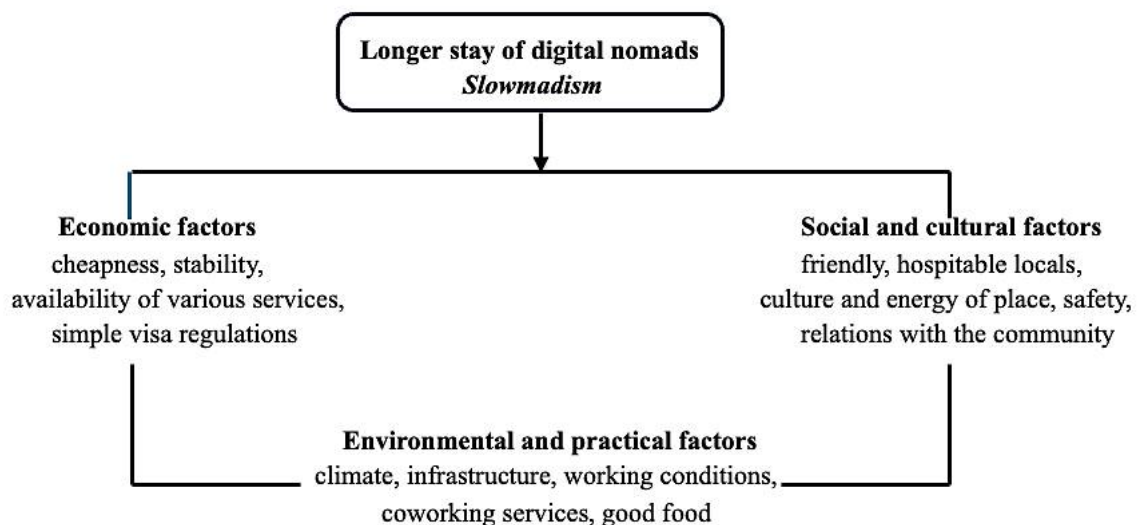


Figure 1. Factors influencing slowmadism.

Source: own elaboration based on research.

These factors can be classified as economic, socio-cultural, and environmental-practical. The study results indicate that economic factors (including affordable living costs) and socio-cultural factors (such as a friendly local community and the opportunity to build relationships) strongly influence the decision to stay longer.

5. Discussion

So far, there has been no research in the scientific literature examining the factors that influence digital nomads to stay longer than the typical duration in a destination. However, some of the factors identified by respondents in this paper align with location attributes recognized in earlier studies as crucial for attracting traditional digital nomads. The study confirmed previous findings by other authors, indicating that digital nomads are more likely to choose locations that provide favorable conditions for remote work, including fast and stable internet access and coworking infrastructure (Orel, 2021; Lhakard, 2022). This result aligns with the concept of digital work. The duration of stay does not influence the necessity for access to a reliable internet connection in order to perform work duties.

Among cultural factors, significant importance was attributed to the location's atmosphere, local culture, and regional cuisine, strengthening emotional connections with a given space. Furthermore, respondents emphasized the importance of simple visa and administrative procedures, facilitating longer stays in the destination country. Researchers in academic studies have emphasized the significance of visa policies for digital nomads, enabling them to travel frequently and freely. To attract groups of digital nomads, some destinations provide specially tailored visas for mobile workers (Chevtaeva, Denizci-Guillet, 2021). This study shows that having a straightforward visa policy along with the option to extend stays are essential conditions for facilitating slowmadism.

Referring to the concept of slow tourism, the main research topic of the phenomenon was travel motivations and the external and internal factors influencing the desire for slow exploration (Dickinson, Lumsdon, Robbins, 2011). Based on the conducted research, one element influencing both slow tourism and slowmadism is a cultural factor that involves engaging with the lives of local residents (Klarin et al., 2023). Some digital nomads expressed a strong desire to connect with the local community and immerse themselves in the daily routines of its members. This is consistent with the general knowledge about the factors influencing the success of a destination, understood as an area capable of attracting and retaining selected groups of recipients, where the support of the local community is essential (Bornhorst, Brent Ritchie, Sheehan, 2010). Residents are the primary group of co-creators of the city's image, presenting the authenticity and uniqueness of a given place (Casais, Monteiro, 2019).

6. Conclusions

Based on the study, several important conclusions can be drawn regarding the factors influencing digital nomads' decisions to extend their stay in a given location. First, one of the most frequently cited reasons is the competitive cost of living. Digital nomads choose cities that allow them to enjoy good living and professional conditions while maintaining relatively low expenses.

Secondly, the friendliness and kindness of residents and the community's openness, which facilitates establishing relationships and building networks, proved equally important. This means that digital nomads are not only looking for places offering attractive working conditions in exotic surroundings, but also for a social anchor. Nomads desire to participate in local life, events, and activities that give them a sense of belonging to a community.

Based on the results, practical implications can be formulated for local authorities and municipal institutions striving to increase the attractiveness of their cities to digital nomads. Primarily, ensuring competitive short-term rental prices and flexible accommodation options is necessary, enabling stays without needing long-term contracts. It is also advisable to support entrepreneurs operating coworking spaces, which provide an important base for remote work. In terms of marketing communications, it is recommended that the city's image be shaped as a place with reasonable living costs, openness, and cultural friendliness. Achieving this goal requires collaboration with local social organizations, which can help build awareness of the benefits of digital nomads for local development. Another important direction for city authorities is strengthening local identity and culture, which form the basis of a city's unique image. Organizing and promoting local events can serve a dual purpose: on the one hand, it strengthens the ties and identity of residents, and on the other, it facilitates contact with local culture and community integration for visitors, including digital nomads.

This study makes a valuable contribution to the knowledge of a new, evolving form of digital nomadism: slowmadism. The constantly growing number of digital nomads and their presence in destinations impacts many aspects of the functioning of territorial units, local economies, and the lives of residents. Therefore, it is crucial to monitor this phenomenon and conduct research regarding this evolving trend. The results presented in this paper may be important for urban planners, sociologists, private businesses as co-creators of urban offerings, and, above all, local city authorities.

The most significant limitation of the study is the remote nature of the interviews, which could have impacted both the researcher's interpretation of the data and the credibility and authenticity of the respondents' statements. It should be emphasized, however, that researching an international group of digital nomads is a demanding undertaking, often dependent on membership in local communities and nomadic groups operating in specific cities.

As a direction for further research on the slowmadism phenomenon, the need to expand analyses to include a quantitative component that would enable estimation of the scale of extended stays by digital nomads and determine the percentage of them who declare a willingness to revisit a similar experience. This would allow for capturing the dynamics and directions of the evolution of the slowmadism trend globally.

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INTERNAL AUDIT OF THE APPLICATION OF SOCIAL ASPECTS IN PUBLIC PROCUREMENT ON THE EXAMPLE OF TENDERS FOR SERVICES

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Purpose: The publication presents the results of a study on the application of social aspects in public procurement on the example of service tenders in Poland. The article also includes, as an additional objective, information on the importance and role of internal audit in evaluating the public procurement process. In addition, it covers the essence of social aspects in public procurement.

Design/methodology/approach: The purpose of the study was achieved by reviewing 2191 public procurement notices that were published between January 1 and December 31, 2024 in the Public Procurement Bulletin. The theoretical issues addressed in the publication included the issue of social aspects in public procurement and the role of internal audit in evaluating the process. The subject scope of the publication includes the results of the scope of application of social aspects in the 2191 public procurement notices examined. The examined announcements included tenders for services.

Findings: The study showed that a total of 842 service tender announcements included social aspects, which accounted for 38.43% of all reviewed announcements.

Research limitations/implications: A limitation of the research conducted was the difficulty in accessing all the data on the public procurement procedures examined.

Practical implications: The results of the study may inspire public authorities to increase the use of social aspects in service tenders. In addition, the publication points to the role of auditing as a tool for evaluating the public procurement system.

Originality/value: The publication contains significant analyses of the evaluation of the scope of application of social aspects in service tenders in Poland. In addition, the paper indicates the possibilities of using internal audit in this process.

Keywords: internal audit, social aspects, public procurement, sustainability, public finances, social procurement.

Category of the paper: Research paper.

1. Introduction

The public sector, in carrying out its tasks, finances them with collected tributes (taxes and fees). Expenditures from the budget for specific public tasks are carried out by both governmental and local governmental entities, as well as by other organizations subordinate to them. Public funds should be spent by the public sector purposefully, efficiently and transparently. They primarily cover the operating costs of these organizations resulting from the implementation of public tasks, which require the purchase of needed goods and services for this purpose (Fisher, 2022). Purchases of goods and services by public entities should be carried out within the framework of standardized rules and procedures defined by the relevant footnotes of the law (Ankersmit, 2020). This is ensured by the public procurement system, which operates in many countries including those of the European Union. The rules for the purchase of goods and services by public entities are regulated by the relevant laws in this regard (The EU Parliament, 2014). It should be noted that public procurement performs a very important function in the management of public finances and enables commercial entities to provide goods and services in accordance with the needs reported by public entities. They also aim to make individual publicly funded contracts accessible to all entities that can provide the good or service in accordance with the requirements specified in the tender. Organizing purchases through tenders should ensure the high quality of goods and services purchased at relatively low prices. The selection of the best-priced offer makes it possible to spend public funds more effectively and manage public resources more efficiently (Hyman, 2011). In addition to the transparent and competitive fulfillment of the public sector's demand for goods and services, the public procurement system also performs other important functions. Relevant regulations require public entities to use various criteria for evaluating bids when selecting a supplier of goods and services.

Public procurement in European Union countries is also an important tool for implementing the principles of sustainable development (Gutiérrez-Goiria, Amiano-Bonatxea, 2022). In addition to environmental aspects, sustainable development places great emphasis on social aspects, related to the fight against poverty and the integration and involvement of many excluded groups (Yumnam et al., 2024). European Union member states, as part of the implementation of sustainable development principles, have made it mandatory to include social aspects in the public procurement system (The European Commission, 2021). Social aspects in tenders can be applied to both the supply of goods and services. The possibility or even the requirement for public entities to apply an appropriate social clause in the case of tenders for services, for example, increases the pressure on business entities to hire employees on the basis of labor contracts. In addition, it contributes to changes in the labor market, as it increases the employment of excluded people, including those with disabilities, or the homeless (Schimanek, 2021). The largest scope of practical application of social clauses

in tenders is in the area of service contracts. The services are performed for the public entity by employees of the company selected in the tender. The public entity may specify in the tender the requirement to hire specific employees to provide specific services, such as catering, cleaning or security of public facilities (Brzychcy, 2022). Introducing the possibility of applying social aspects in public procurement requires exercising control over the process. The entity overseeing the public procurement process in Poland at the national level (the President of the Public Procurement Office) should implement audits and controls in this area. Only an audit or inspection of the assessment of the application of social clauses can make it possible to verify the extent of their application in individual tenders, including for the provision of services. In addition, individual public entities should conduct internal audits in the area of public procurement. It should be noted that internal audit is an independent cell within a public organization that evaluates the various processes implemented by it (Przybylska et al., 2024). Internal auditors can conduct audit activities to verify the application of social clauses by a given public entity in organized tenders for services, supplies or works (Yanuarisa et al., 2025).

The purpose of this publication is to present the results of an assessment of the scope of application of social aspects in tenders organized by public entities for services. The choice of public procurement procedures for services was based on their specificity and relevance to the issue under study. Services provided to public entities are performed by employees of business entities that bid for the contract in question. In addition to defining the purpose for the purpose of the publication, the hypothesis was adopted that social aspects in service tenders are applied to a limited extent. The verification of the hypothesis and the realization of the objective will be carried out in the publication by analyzing the public service contract award notices that were published in 2024 by public entities in the Lodz Voivodeship in Poland.

2. Social aspects in public procurement

Sustainable development is a concept that has been developed since the second half of the 20th century, however, the landmark document in this area was the Brundtland Special Report produced in 1987 (Brundtland Gro Harlem, 1987). It was a response to emerging environmental and social problems that were growing as a result of dynamic economic development. The issue of sustainable development is now a very important area of activity for commercial and public entities. Caring for the environment and eliminating social disparities are key goals to be achieved for European Union countries. The principles of sustainable development are implemented in many areas of a country's activities, one of which is the policy of purchasing goods and services by public entities (Drosik et al., 2022).

Public procurement plays an important role in the practical implementation of the principles of sustainable development (Manta et al., 2022). The implementation of these principles includes social issues in addition to the typically environmental aspects, such as reducing carbon emissions. Social aspects are included in the goals of the 2030 Agenda for Sustainable Development (Yumnam et al., 2024). One of them is Goal 10 - less inequality. It includes in its scope such issues as social, economic and political inclusiveness for all people, regardless of age, gender, disability, race, ethnicity, nationality, religion or economic or other status (United Nations, 2015). The implementation of these goals is also carried out in the procurement process (Olsson et al., 2021). This is due to the growing importance of ongoing analyses of the social return on a given investment made by a public entity (Vluggen et al., 2020).

Public procurement as a process of purchasing goods and services by public entities plays an important role in the spending of public funds in Poland. It should be noted that public entities play an important role in the market economy as recipients of goods and services provided by the commercial sector. According to the draft Report of the President of the Public Procurement Office, the total value of public contracts awarded in Poland in 2024 was about PLN 330.4 billion (with a figure of about PLN 279.8 billion in 2023). This amount represented about 9.07% of the Gross Domestic Product (GDP), with Poland's GDP estimate for 2024, according to the Central Statistical Office, at PLN 3,641.2 billion. The total value of the public procurement market in Poland was about PLN 587.0 billion in 2024, while, in 2023, it was about PLN 579.7 billion (Public Procurement Office, 2025). The above data indicate that public procurement accounts for a significant share of Poland's GDP and plays a significant role in the market.

The public procurement system assumes, by definition, that all purchases should be transparent and carried out in accordance with the regulations in force in this regard (The legislator, 2019). Poland, like all other member states, has been obliged to develop appropriate legal regulations that set the rules for public procurement. Purchases of services, goods and the commissioning of works should be carried out by public entities in accordance with the regulations of the European Union, national law and internal procedures developed in a given unit of the public finance sector. The bidding procedures of a given institution detail the rules that must be followed throughout the process of planning and implementing purchases of goods and services (Szydłowski, 2022). The rules contained in the procedures and legislation also determine the scope of application of social clauses in the process of evaluating bids submitted by commercial entities in a given tender. The implementation of these clauses makes it possible in practice to implement the principles of sustainable development in social areas (Kowalczyk, 2017).

The public procurement system in the European Union (formerly the European Economic Community and the European Communities) has been in place since the 1970s, undergoing many changes. Initially, it was focused on economic objectives, however, as a result of changes in the world and taking steps to implement the principles of sustainable development, it began

to be supplemented with other aspects. The European Union's efforts to implement the goals of Agenda 2030 resulted in the public procurement system being expanded to include social aspects as well (Florecka, 2023). Social aspects in tenders are applied by member states in the European Union on the basis of the European Commission Directive on public procurement (The EU Parliament, 2014). The adopted rules for public procurement in member states have been expanded to include the need to consider social issues in tenders. The goal of Socially Responsible Public Procurement (SRPP) is to achieve positive social impacts within the public procurement system. Public entities in Poland using social clauses can enable *contractual employment, up-skilling and re-skilling of the workforce, decent work, social inclusion, gender equality and non-discrimination, accessibility, design for all and ethical trade, and strive for broader compliance with social standards* (The European Commission, 2021). Including the indicated aspects in tenders also contributes to the social economy concept. This concept contributes to the implementation of corporate social responsibility. In addition, it leads to changes in the labor market, such as the integration of excluded people (homeless, disabled, unemployed, of a certain age, foreigners), who are more likely to be employed by companies participating in tenders (Ek Österberg, Zapata, 2025). Aiming to integrate people at risk of social exclusion is a key goal of implementing social aspects in tenders (Hebda-Czaplicka, 2021). The social economy also addresses issues of supporting the activities of non-governmental organizations (Chojnacka, 2020). Public entities, by applying selected social criteria in a tender, can support the operation of social enterprises. Social enterprises, unlike typical commercial entities, are established mainly because of and for social purposes (Kozar, 2023). By their activities, these entities contribute to socio-economic changes in their environment. The workforce in social enterprises is usually composed of excluded people who find it difficult to find their way in the labor market. Very often, social cooperatives provide catering services or cleaning of public facilities (Ewelina Florczak, Krzysztof Skrobisz, 2023).

Analyzing the issues at hand, it is worth defining services and their scope in the public procurement system. Services include, first of all, cleaning of premises, protection of property, catering, consulting, translation, training for employees of a given unit of the public finance sector. It will also include services necessary for the implementation of the policies and basic tasks of public organizations such as cleaning services for premises used by the principal (Grandia, Volker, 2023).

The catalog of social aspects in tenders is defined in Poland by detailed regulations contained in the Public Procurement Law of 2019 (The legislator, 2019). Social aspects can be included in tenders in the description of the subject of the contract or in the criteria for evaluation of the offer. The scope of application of social criteria in a given tender depends on the scope of the service in question. Detailed decisions on the application of bid evaluation criteria are made by the public entity awarding the service contract (Brzezinski, 2024).

The scope of social aspects that a public entity can apply in a tender (including for services) includes:

- stipulating in the tender announcement that only an entity with the status of a sheltered workshop or social cooperative may participate,
- employment of employees by contractors only on the basis of a labor contract, in accordance with the Labor Code,
- the requirement for accessibility for people with disabilities and design for all users, including those with disabilities,
- the requirement for the selection of the most advantageous tender submitted as part of the tender that includes social aspects, taking into account the professional and social integration of people who are excluded and at risk of social marginalization, including through their employment by the service contractor (The legislator, 2019).

The above social aspects can be used by procurers to apply to the service to be tendered. The use of the above requirements practically contributes to the improvement of the situation of excluded people and the practical implementation of the principles of Agenda 2030 and the sustainable procurement system (Gutiérrez-Goiria, Amiano-Bonatxea, 2022). However, it is crucial to apply the above aspects in most tenders especially for the implementation of services for public entities (Schimanek, 2021).

3. The role of internal audit in evaluating the performance of public entities

The procurement process is regulated in detail by European Union and national regulations. Ensuring the proper implementation of tenders for the supply of goods and services requires ongoing supervision and control of this process. A very important instrument in this area is the internal control system. Its main purpose is to prevent and eliminate potential risks in the ongoing implementation of tasks and violations of internal regulations and procedures. Various models of internal control are currently in operation, however, public entities in Poland were obliged to implement a uniform system of management control (Paliga, 2023). Management control in Poland was developed according to the Committee of Sponsoring Organizations (COSO) model. The internal control system according to COSO emphasizes risk management systems, procedures, code of ethics, controls, self-assessment and internal audit (Chen et al., 2025).

The process of procuring goods and services for an organization is associated with the occurrence of many risks. It is worth mentioning that a risk is a potential threat that can cause serious problems for the operation of a public organization. In order to counteract this, it is necessary to implement a risk management system that covers all processes implemented

in a public organization (Mujalli, 2024). Practically, the identification of risks and their minimization must take into account the procurement process. This process includes the plan for the purchase of goods and services, the conduct of the tender, and the execution of the resulting contract. The risk management process, on the other hand, includes identifying potential risks, communicating and managing risks. In any process, it is crucial to organically and eliminate diagnosed risks through appropriate controls (Almgrashi, Mujalli, 2024).

The management of public entities should therefore be aware of potential risks in the area of public procurement (Mucha et al., 2023). Risks in public procurement include such issues as non-compliance with laws, corruption, spending of funds contrary to the law and approved plans, selection of the wrong service contractor, and failure of the contractor to meet the terms of the contract (Urbanek, 2018). The materialization of risks in the area of tendering can involve serious legal, financial and image problems for the contracting authority. In addition, failure to comply with procurement laws may result in a violation of public finance discipline. Verification of risks and evaluation of the internal control system is one of the tasks of internal audit (Hay, Cordery, 2018). Virtually every area of an organization's operations should be subject to periodic internal audits and inspections. Only periodic audits make it possible to eliminate risks and improve the procurement process on an ongoing basis (Arens et al., 2017).

Internal audit is a tool for independent evaluation of the processes implemented in an organization. It also verifies the compliance of implemented tasks with legal regulations and the financial management of the organization. Internal audit reports directly to the entity's management, to whom it provides reports on the evaluation of the processes implemented in the organization. Auditors play an important role in evaluating processes, improving them and detecting irregularities, fraud and abuse (Cordery, Hay, 2020).

Internal auditors are an important tool in exercising day-to-day control over an organization. Central to auditing is assessing processes based on risk analysis and examining its management in the audited area. The auditors' assessments and analyses of the audited process form the basis for its evaluation. In addition, internal auditors make recommendations for improving the audited issue, including procurement (Pickett, Pickett, 2010). Internal auditors perform their tasks in accordance with global standards of professional practice. The standards define the mode of internal audit execution and the auditor's work ethics. They also ensure the independence of internal auditors and define the key principles for carrying out their tasks (The Institute of Internal Auditors, 2024).

Internal auditing was introduced in Poland in 2002, as a result of the integration process with the European Union. Legal regulations in this area underwent many changes. Eventually, internal audit was introduced in many public entities as a key tool for evaluating their performance. It also plays an important role in the process of evaluating the risk management system and management control in public finance sector entities where it has been implemented (Winiarska, 2018). The scope of internal auditors covers all areas and processes implemented in a given unit of the public finance sector.

Internal auditors carry out an assessment of the implementation of the procurement process, which is an important area of activity for any public finance sector unit. This area, as already indicated, is exposed to many risks and requires periodic assessment of internal auditors. The analysis of the literature clearly indicates that auditing the procurement process is one of the key areas of internal audit activity. Public procurement is audited in many countries around the world. This area represents very important issues for stakeholders in every country. Conducting transparent tenders is one of the pillars of democratic governance. In addition, public procurement is linked to the process of spending public funds on investments, purchases of goods and services. It should also be emphasized that the spending of public funds in a tender from the state or local government budget is exposed to the risk of corruption. Internal audit is a very important independent assessment of this process and identification of risks in this area (Yanuarisa et al., 2025).

The procurement process is conditioned by a number of legal, financial and organizational requirements. The public sector's implementation of sustainable procurement makes it necessary to prepare a tender that takes into account environmental and social aspects (Hafsa et al., 2021). Specifying in the regulations the requirement to apply social aspects during the tender requires control of their application. To this end, tendering procedures are developed that include rules for applying social aspects. Conducting tenders and adhering to internal regulations and procedures requires control over them. The optimal tool for evaluating the application of social aspects in tenders is an internal audit (Lagström, Ek Österberg, 2025). An internal audit of social aspects in service tenders can provide the entity's management with key data in this regard. When carrying out an audit assignment, internal auditors review the documentation of executed service tenders. During their audit activities, they assess the legitimacy of the selection and application of a particular social aspect. They also verify the compliance of implemented activities with the procedures defining the rules for conducting tenders. Auditors also analyze the reasons why the social aspect was not applied in the audited tender. The decision to apply the social aspect is made at the preparation stage of the tender (Adjorlolo et al., 2025). Thus, it requires internal auditors to examine the preparation process of the tenders under review. Auditors also evaluate the extent to which social aspects are applied in tenders issued by a public entity. Another area of evaluation is the selection of a particular social aspect, its legitimacy, expediency and compliance with legal regulations (Matas et al., 2025). Internal auditors evaluate the process of selecting the most advantageous offer in a given tender for services in accordance with the requirements specified in the tender announcement and the description of the subject of the contract. An important issue under evaluation is how to document and control the regulations included in the contract. These regulations usually concern the definition of specific social aspects, for example, the contractor's employment of employees performing the service under a labor contract. Assessment of the scope of application of social clauses in tenders was the subject of an internal audit in 2018. This audit was commissioned by the Ministry of Finance. It covered 126 government entities. The study

concerned the evaluation of the implementation of social aspects in tenders after their introduction as a result of changes to the regulations in this area. The results of the audit proved that 62% of tenders at the stage of their preparation assessed the possibility of applying social aspects. This could indicate the actual implementation of sustainable public procurement in Poland with regard to the application of social aspects in tenders (Ministry of Finance, 2020) (MF Report). Internal audit is therefore an appropriate tool for assessing the application of social aspects in public entities.

4. Description of the research method

The purpose of the research included in this publication was to verify the scope of application of social aspects in tenders organized by public entities for services. The research hypothesis was also established that the scope of application of social aspects is limited. For the purpose of achieving the goal and verifying the hypothesis, the announcements on the awarding of public contracts for services that were published in 2024 by public entities in the Lodz region of Poland were analyzed. Research for the purpose of the publication was carried out using descriptive statistics, a case study and the methodology used by internal auditors for the examination of documents (service tender announcements). The study of the scope of application of social aspects in tenders was carried out on the basis of service tender announcements. All service tender notices that were published by public entities on the website of the Public Procurement Bulletin between January 1 and December 31, 2024 were analyzed (e-Procurement, 2025). Announcements on the award of public contracts for services to be carried out under the limited national mode were evaluated. The award of public procurement under the national mode is more simplified. This is due to national and European Union regulations, in which there are specific amount thresholds below which the simplified mode can be used. It is worth pointing out that the amount thresholds for services in 2024, below which the national simplified tender mode could be used, were:

- EUR 143,000 (PLN 663,105) for entities in the public finance sector that are not local governments, universities or cultural institutions, as well as for state organizational units without legal personality,
- 221,000 euros (1,024,799 PLN) for other public procurers, i.e. local government units, public universities and their unions, state cultural institutions,
- 750,000 euros (PLN 3,477,825) for social services (The legislator, 2019).

The use of the national simplified mode in the practice of public procurement accounts for the largest share of the total number of tenders, so their analysis in the studied area was justified. This is because the examination of published announcements made it possible to check the actual scale of application of social clauses in tenders for services.

Verification of the research hypothesis required analysis of homogeneous entities that published public contract award notices. For this purpose, a homogeneous group of public entities was selected for the study. With the above criteria in mind, for the purposes of the study, public service contract award notices published by public entities under the simplified national mode were finally selected for analysis. The study included all 2191 public contract award notices from the Lodz region that were published in the Public Procurement Bulletin in 2024 (e-Procurement, 2025).

Simplified rules for national public procurement include various social aspects that can be applied by public entities, according to the regulations. Examination of service tender notices in accordance with the national procedure procedures included thorough verification of the application of a specific social aspect. The evaluation included the application of social aspects in the description of the subject of the contract and the tender evaluation criteria adopted in the tender. Analysis of the announcements made it possible to determine the practical extent of the use of social aspects in service tenders. Examination of all 2191 announcements made it possible to develop a statistical summary of the scope of use of social clauses in service tenders. It is worth noting that service tenders accounted for 27% in 2024 (28% in 2023) of the value of contracts awarded in Poland (Public Procurement Office, 2025).

The review of tender notices was aimed at determining the overall scale of application of social criteria in the description of the subject of the contract and in the criteria for evaluating bids submitted by potential service contractors. In addition, the extent of application of the various social aspects specified by the legislator in legal regulations was examined. The analysis of announcements made it possible to examine the actual scale of application of social criteria in service tender announcements. The results of the analysis are presented in the following part of the work in the form of a tabular summary with a description.

5. Results of the analysis of the scale of application of social clauses in tenders

The survey of 2191 announcements of public entities on the award of public contracts for services made it possible to compile the results presented in this part of the publication. A general summary of the number of tender notices containing social aspects along with the percentage is presented in Table 1.

Table 1.

Summary of the total number of public procurement notices for services with social aspects that were examined

Item	Numerical and percentage coverage of public procurement notices examined	
	Number of public procurement notices for the provision of services	Share of type of public procurement notice in %
Total number of public procurement notices examined	2191	100%
Public procurement notices with social clauses	842	38.43%

Note: The study covered a total of 2191 public procurement notices that were published by public procurers (central and local government offices, public universities, health care institutions, research institutes, higher education institutions and by other public entities obliged to do so) from the Łódź Province in Poland between January 1 and December 31, 2024 on the website of the Public Procurement Bulletin (e-Procurement, 2025). Table 1 also includes a total of 842 service tender notices that included social aspects.

Source: own study based on empirical research.

Based on the data in the table (Table 1) containing the results of the analysis of 2191 service tender notices, it can be concluded that social aspects were included in a total of 842 notices. The service tender announcements were published by public entities from Lodz region in Poland in 2024. The tender notices examined were for public procurement procedures in a simplified national procedure. The percentage of tender notices containing social aspects totaled 38.43%. This demonstrates the limited scope of application of social criteria in service tenders by public entities. In addition to a general determination of the scale of application of social criteria in service tender notices, an analysis was conducted on the use of specific social aspects. A detailed summary showing the use of specific social aspects by public entities in service tenders is presented in the table (Table 2).

Table 2.

Summary of numbers and percentages of public procurement notices containing certain social aspects under the provisions of the PPL Act

Item	Numerical and percentage coverage of the public procurement notices examined regarding the application of specific environmental criteria under the PPL		
	Number of public procurement notices awarded for services	Percentage of notices with selected environmental aspects from the PPL in the total number of notices (2191)	Share of notices with a selected environmental aspect from the PHP in the total number of green public procurement notices (842)
Notices in which social aspects were included in the description of the subject of the contract	75	3.42%	8.91%
Notices containing social aspects in relation to the tender evaluation criterion	93	4.24%	11.05%
Announcements in which the draft contract included social aspects related to the implementation of the public contract	755	34.46%	89.67%

Cont. table 2.

Announcements containing, in accordance with Article 94 of the Act, a reservation that entities with the status of a sheltered workshop, social cooperative or other	52	2.37%	6.18%
Announcements containing a social aspect regarding the requirement to employ workers on the basis of an employment relationship, in accordance with Article 95 of the Act	729	33.27%	86.58%
Announcements containing an aspect under Article 96 of the Law - social aspects	55	2.51%	6.53%
Announcements containing the aspect of accessibility for persons with disabilities and design for all users, in accordance with Article 100 (1) of the Law	79	3.61%	9.38%
Announcements containing the requirement under Article 242(2) of the Law, i.e., selection of the most advantageous offer taking into account social aspects	65	2.97%	7.72%

Note: PPL stands for the specific legal regulations contained in the Act of September 11, 2019. Public Procurement Law (Chancellery of the Sejm of the Republic of Poland, 2019). The study covered a total of 2191 public procurement notices published by public procurers (central and local government administration offices, public universities, health care institutions and local government administration offices, public universities, health care institutions, research institutes, higher education institutions and by other public entities obliged to do so) from Łódź Province in Poland between January 1 and December 31, 2024 on the website of the Public Procurement Bulletin (e-Procurement, 2025). The table (Table 2) summarizes the number and percentage of notices that included specific social aspects resulting from the legislation governing the public procurement system in Poland. In the surveyed population, a total of 842 notices containing the social aspects indicated in detail in the above table (Table 2) were identified.

Source: own study based on empirical research.

In accordance with current legislation, a public entity may apply a social aspect in the description of the subject matter of the contract, in the criteria for evaluating bids and in the regulations of the draft contract for the service. The available catalog of social aspects includes, first of all, the requirement to employ employees performing the service on the basis of an employment contract, employing excluded and disabled people, limiting the contractors of the service to selected entities (e.g., social cooperatives), or designing the service taking into account accessibility requirements for people with disabilities. The choice of a particular social aspect in practice depends on the specifics of the service. Formally, the selection of the social aspect is decided by the head of the public finance unit conducting the tender. The decision to apply the social aspect in the tender procedure is made at the stage of its preparation. The substantive employees of the organizational units of the public entity, while preparing the tender, decide which social aspect to apply. The choice is made depending on the scope of the service planned to be commissioned under the tender and the applicable law. Very often the decision is made not to apply the social aspect in a tender for services, as indicated by the data in the table (Table 1). Of the 2191 service tender notices examined, social aspects were not applied in 1349 proceedings, which accounted for 61.57% of all notices.

The data in the table (Table 2) includes the results of an analysis of the use of social aspects specified in the law by public entities in the surveyed tenders (The legislator, 2019).

According to the data in the table (Table 2), public entities most often specified the social aspect in detail in the draft contract for a given service. A total of 755 service tender announcements included information that the draft contract stipulates the application of the selected social aspect. The inclusion of the social aspect in the draft contract accounted for 89.67% of the total number of 842 announcements with social aspects. The indicated numerical value represented a 34.46% share of all 2191 notices examined. It should be added that the draft contracts contained annotations regarding the rules for controlling the fact that the service contractor applied a social aspect. For example, draft contracts for the implementation of security or cleaning services stipulated the requirement for the service provider to provide confirmation of the employment of employees on labor contracts in accordance with the Labor Code. The public entity awarding the contract reserved in the draft contract the right to control the fact that contracted employees were hired to perform the service. In addition, the contracts included contractual penalties or other sanctions in case the contractor failed to comply with its regulations on social aspects.

Another social aspect used by public entities in service tender announcements was the requirement to hire employees on a labor contract. This requirement for potential service providers was included in a total of 729 tender notices. This figure accounted for 33.27% of the share of announcements with this social aspect in the total number of announcements examined. The requirement to hire employees based on an employment contract accounted for a share of 86.58% of the total number of announcements with social aspects. The significant extent of including this requirement (social aspect) in advertisements may have a positive impact on the labor market. It should be considered an attempt by the public sector to influence entrepreneurs in normalizing hiring rules. The requirement to hire employees performing services under contract for public entities is an important signal to employers. This is because it means that the public sector, for which the service is to be performed, requires that employees be treated on similar terms to those that apply to public finance sector entities. The social aspect in question is important for increasing the scope of legal employment of employees under the Labor Code, which can limit unethical practices of companies in this area. In addition, it indirectly contributes to increasing tax revenues and contributions paid by employers under the social security system.

Social aspects as a criterion for evaluating bids in service tenders were used in 93 announcements out of 2,191 examined. This accounted for a share of 4.24% among all the advertisements examined, and an 11.05% share in advertisements with social aspects. The use of only 93 ads as an evaluation criterion for social aspects should be considered decidedly low. The low use of the aspect in question as an evaluation criterion may mean that social aspects in practice do not play a major role in the preparation of tenders for services by public entities.

Ensuring accessibility for people with disabilities along with designing a good or service for all recipients was applied in 79 announcements containing social aspects. These notices accounted for 3.61% of all notices examined and a 9.38% share of notices with social aspects. The identification of this aspect in the tender announcement was mainly related to services for transporting people, including those with disabilities, catering, cleaning of premises, and postal services. In addition, the aspect in question concerned services related to the preparation of street signage, repair and maintenance of street lighting. The inclusion of the above social aspect in the tender for services was intended to ensure that the service provider took into account the needs of people with disabilities.

Contracting authorities included social aspects in the description of the subject of the contract in 75 tender notices. This represented only 3.42% of all tender notices examined and 8.91% of notices with social aspects. The insignificant extent of the use of the social aspect in tenders in the description of the subject of the contract indicates that social sustainability criteria are used to a small extent by public sector organizations in the area of service tenders.

The selection of the most advantageous offer with the need for the contracting authority to include the social aspect criterion was included in only 65 announcements analyzed in total. This represented the share of tender notices in the total number examined at 2.97%. Moreover, this value accounted for 7.72% of all announcements containing social aspects. The sporadic use of social aspects as one of the qualitative criteria in the selection of the best offer may indicate the still low awareness of the issue in question among public managers. This perception of social aspects may adversely affect the increase in their use in service tenders.

The requirement to document the service contractor's fulfillment of certain social aspects (as defined in Article 96 of the Law) was applied in 55 notices out of all those analyzed. This represented 2.51% of all advertisements examined and a share of 6.53% of advertisements with social aspects. The regulation in question in the announcement imposes an obligation on the potential contractor to document the contractor's fulfillment of requirements, e.g., employment of employees under an employment contract. In addition, the powers of the public entity to control the contractor's fulfillment of the requirements specified in the tender are established, as well as sanctions for non-fulfillment. Analyzing the tender documentation, it can be seen that this mainly concerned the requirement to hire employees on a labor contract, along with the required number of employees. For example, social aspects in this regard relate to tenders for security, catering or cleaning. The contracting authorities then specified a minimum number of disabled employees to perform the service. The use of this legal regulation in the announcement means that preference is given to businesses that employ disabled or excluded people. Such measures contribute to the integration of people at risk of social exclusion. In addition, they can encourage employers to hire excluded and disabled people. The very limited application of the regulation in question to social aspects may indicate that public entities are still not using this regulation on a wider scale.

The last social aspect applied in only 52 service tender notices was the restriction (regulation of Article 94 of the Act), of participation in tenders to entities with the status of a sheltered workshop or social cooperative. This aspect accounted for only a 2.37% share of the total number of all service tender notices. Limiting the catalog of entities that can participate in the tender was applied to only 6.18% of all announcements with social aspects. A social aspect limiting contractors for a given service to social cooperatives or sheltered workshops may contribute to the development of these entities. This will only be possible if the frequency of application of this legal regulation in tenders for services announced by the public sector increases.

The issue of social aspects is linked to corporate social responsibility, as mentioned by researchers in their publications. The application of social aspects in public procurement encourages companies to improve the social impact of their activities on the environment. Sustainable public procurement can contribute to increasing the importance of corporate social responsibility. This calls for a change in the approach of the European Commission on this issue, which should ensure that sustainable public procurement is more closely linked to the social responsibility of business, both socially and environmentally (Ankersmit, 2020). In addition, it should also be noted, social aspects in tenders play an important role in building social capital (El Bizri et al., 2023).

6. Discussion

Public procurement plays a very important role in the economy and the public sector can influence the economy through it. In addition, they contribute to many changes in the market in many areas. For example, the use of social aspects in tenders as a criterion for evaluating bids leads to the integration of excluded people. The results of the research presented in this publication showed that in Poland, social aspects are used to a limited extent in tenders for services. The discussed issues of public procurement and the use of internal auditing in their evaluation are the subject of research in many countries.

A study covering Denmark, Sweden and Finland on socially oriented public procurement showed that the political context should influence the use of social aspects in public procurement. This included sustainable public procurement. The results of the research did not confirm the exchange of good practices between Denmark, Sweden and Finland in the implementation of sustainability in public procurement. According to the researchers, this may have resulted in a loss of efficiency in the public procurement system. The research also found that in many tenders that took social aspects into account, price was the key criterion for selecting a contractor (Wising, 2021). This may indicate that social aspects are not the only ones used by contracting authorities in tenders to a limited extent in Poland.

The public procurement system can be used to create social value. Research in this area included 17 case studies of public sector institutions in the UK (Metropolitan Councils and hospitals). The result of this research was to diagnose how social value policies translated into strategic procurement goals and actions. The researchers related social value to the economic, social and environmental well-being of the community in which the evaluated public sector operated. According to the researchers, social value manifests itself in a diverse set of outcomes. These include social inclusion (including disadvantaged minorities), employment and training, decent working conditions, access to public procurement for small and medium-sized businesses, environmental protection and ethical conduct in supply chains. The research focused on public services for the performance of which the analyzed entities organized tenders. The results presented showed that public procurement can create significant social value. In addition, it was proven that the cooperation of public entities facilitates the implementation of strategies. In addition to this, it was also established that sharing resources and knowledge helps in terms of social value creation. Important in this process was the use of social aspects by procurers in the tenders conducted (Selviaridis et al., 2023).

Also in Poland, the use of social aspects in tenders is a research area. Polish legal regulations allow the use of social aspects as a criterion for evaluating bids in tenders. However, practice shows that public entities in Poland are reluctant to use them in their tenders. The use of social aspects in tenders, such as the requirement for the service provider to hire employees under an employment contract, increases employment and employment stability (Sack, Sarter, 2022). Social aspects in tenders also contribute to greater integration of excluded people and spread decent employment. In addition, they also lead to a righteous quality of life, particularly for people with disabilities. Thus, it should be recognized that the scope of application of social aspects should be much greater than at present (Brzezinski, 2024). To some extent, the above conclusions were confirmed by the results of a survey of public service contract award notices, which are described in this publication.

Public entities in the public procurement market play an important role around the world. Decisions made by public managers to apply social aspects in tenders can influence the behavior and decisions of entrepreneurs. Analyses in this area are also of interest to many researchers. Some of them declare that public entities have the potential to increase overall social benefits through social public purchasing. They also recognize that social public procurement is a strategic tool used by both the domestic public sector and international organizations (e.g., UN, EU) around the world. Public entities implement this mainly to influence social outcomes. It is worth noting that the United States of America uses social aspects in public procurement for various disadvantaged communities (e.g., the excluded). Other countries around the world are also using social procurement policies to help disadvantaged communities. Appropriate definition of social aspects in public procurement enables impact on various important social and economic areas, such as the labor market, and integration of socially excluded people (Hafsa et al., 2022).

Social aspects in public procurement contribute to making unemployed people more active. A good example is a case study from the city of Gothenburg, Sweden. The case studied was to develop a local model - "Social Issues in Public Procurement". The target group of the social procurement program was the unemployed, who received support from the local government. The program had a positive impact as a result of the implementation of a wide set of measures that contributed to the improvement of social procurement. Priorities and criteria for evaluation in tenders were established, which enabled local businesses to adapt their offerings to the requirements of public entities. The adaptation of businesses to the requirements of the local public sector made it easier to win contracts from these public entities through tenders. Businesses have hired unemployed people from the local labor market in order to carry out the contracts concluded under the tenders. This is a good example of cooperation between the public sector and entrepreneurs. This cooperation made it possible to develop tender requirements and bid evaluation criteria that included social aspects. The result of these activities was to increase the level of employment in the local community (Ek Österberg, Zapata, 2025).

Individual EU countries are striving to implement social clauses in public procurement in practice. To this end, the European Commission publishes best practices in this area. The benchmarks for tenders with social clauses presented in the EU publication clearly indicate that they concern the implementation of programmes by public administration (central and local government). In addition, EU Member States have made many changes to their tendering procedures, increasing the scope of application of social clauses. For example, between 2014 and 2018, the Walloon Region in Belgium applied social clauses in 442 contracts (with a total value of almost EUR 400 million). As a result, 410 internships were created and 70 contracts were concluded with subcontractors that are social enterprises. France, on the other hand, introduced an obligation to develop a public procurement strategy for buyers in markets with a minimum annual turnover of EUR 100 million (excluding VAT). As a result, almost 160 local authorities are potentially involved in the programme, i.e. almost all regions of France, around 60 departments, almost 70 public inter-municipal cooperation institutions and around 10 municipalities with a population of over 250,000 each. Among the best EU practices in this area, an example from Poland was also described. It concerned a contract concluded for the provision of cleaning services for the Municipality of Wrocław (Wrocławskie Mieszkania Limited Company). The contract covered cleaning in the premises and facilities of the Municipality of Wrocław. The tender announced for the indicated service was addressed exclusively to social cooperatives. Wroclawska Social Cooperative was selected in the tender. As a result, 12 people in difficult life situations, mainly from homeless centres in Wrocław, were able to participate in the process of their integration into the local community (Caimi et al., 2019). An analysis of benchmarks in the use of social clauses clearly indicates the need for effective action by the EU authorities to implement and promote them. Furthermore, failure

to introduce a uniform requirement to use social clauses in all tenders within the EU will make it difficult to increase their use by the public sector.

The issue of conducting an internal audit of public procurement has been addressed by many researchers. An evaluation of publications in this area indicates that conducting an evaluation of tenders by independent internal auditors is very important. A publication reviewing the literature in this area proves that internal auditing is important for improving the procurement management process. Audit's tasks in this area focus on promoting transparency, accountability and efficiency. The publication also proves that internal auditors' use of modern information technology to evaluate public procurement improves fraud detection and increases the efficiency of their operations. Currently, the key problems of internal audit in the day-to-day execution of tasks are limited resources, insufficient institutional capacity and inadequate training for internal auditors (Yanuarisa et al., 2025).

Internal audit's procurement assessment activities will increasingly be supported by artificial intelligence. The possibility of using artificial intelligence in the work of internal auditors is being taken up by researchers. Publications in this area indicate that its use can improve the efficiency and effectiveness of the work of internal auditors and controllers in assessing the implementation of processes by the public sector (Genaro-Moya et al., 2025). Modern information technology also makes it possible to detect corruption in the procurement process. This process is subject to the risk of corruption and fraud. The possibility of using information technology in this regard is described in publications on the public procurement system in developing countries. One publication in this area argues that internal auditors can be helped by the use of blockchain technology. The case study described in the publication concerns its application in the procurement process in Ghana. The technology in question has been adopted in Ghana as a new best practice in public procurement. It should be mentioned that blockchain technology enables streamlined management by increasing transparency, accountability and operational efficiency in procurement processes. The technology is very helpful to internal auditors in conducting assessments of public procurement performance, including the detection of fraud and corruption. The technology's capabilities also ensure effective service delivery and practical implementation of sustainable development principles (Adjorlolo et al., 2025).

Internal audit plays an important role in evaluating the procurement process. The result of the auditors' work is the issuance of an assessment regarding the audited process and the presentation of recommendations to improve the audited area. The public procurement system can only function well if the recommendations made by internal auditors are implemented. This applies to any area of public procurement including social aspects. The problem of implementing internal procurement audit recommendations was the subject of a study in Tanzania. As a developing country, Tanzania faces many problems including the functioning of the public procurement system. The survey covered 51 procurement entities in Tanzania (including ministries, departments, agencies and local governments). The findings described in

the publication indicated that insufficient implementation of internal audit recommendations in Tanzanian public procurement entities was due to ineffective mechanisms for monitoring their implementation. In addition, auditees' failure to implement recommendations was due to insufficient resources needed to implement them. Another factor was the lack of involvement of public managers in implementing procurement recommendations (Yussuf et al., 2024).

Generalizing, internal audit plays an important role in evaluating the procurement process. In addition, it can be effectively used to evaluate and control the application of social aspects in public procurement. Social aspects properly applied in tenders by the public sector can be a good tool for implementing the principles of sustainable development included in Agenda 2030.

Conclusions

Conducting assessments of the implementation of public procurement by internal auditors is an important tool for oversight and control of the process. Internal audits can be conducted to evaluate the entire procurement process or selected aspects. One of these audit areas is the evaluation of public entities' application of social aspects in tenders.

The procurement system is an important area for control and audit in public entities. Social aspects in tenders require a separate approach and evaluation. This is due to the peculiarities of the issue and their connection with the principles of sustainable development. It should be noted that they play an important role in the integration of excluded people. The inclusion of a social aspect in the bid evaluation criteria influences certain decisions made by entrepreneurs willing to participate in the tender. For example, the need to comply with the requirement to hire employees performing certain services for the public entity on a labor contract can affect changes in the labor market. The impact of social aspects in tenders on social capital and the labor market is of interest to many researchers. Research in this area clearly indicates that they enable the actual integration of excluded people. In addition, they have a positive impact on the perception of this issue by the public sector and entrepreneurs. Unfortunately, still the scope of application of social aspects in public procurement is limited. This was confirmed by the research conducted and the analysis of the literature in this area.

Increasing the awareness of public managers of the importance of social aspects in public procurement requires that public authorities undertake wider promotional activities. A separate issue is the evaluation of their actual application in tenders. The application of social aspects in tenders must be subject to periodic audits and inspections. The optimal tool in this regard is internal audit, which objectively evaluates the correctness of the implementation of the procurement process. Internal auditors, in addition to examining the correctness of the bidding process, make recommendations to improve the audited process. An independent assessment

of those not involved in the tendering process makes it possible to detect errors, non-compliance with regulations and irregularities, including those involving fraud or corruption. When performing an audit task in the area of public procurement, internal auditors assess the risks involved. In addition, they are engaged in identifying and estimating risks in the organization in which they operate. In practice, this is crucial for the proper execution of tenders. This is because awareness of the risks associated with a given process enables the organization's management to apply appropriate controls to reduce or minimize the identified risks.

An analysis conducted for the purpose of this publication of the scope of application of social criteria in service tenders showed that they are used to a limited extent in Poland. An examination of 2,191 service tender notices (published in 2024) showed that social aspects were applied in a total of 842 proceedings. This represented 38.43% of all service tender notices examined. The most frequently used social aspect in tenders was the requirement that the service provider hire employees on a labor contract. The least frequently used social aspect in service tenders was organically in the criteria for evaluating the offers of potential service providers to social cooperatives and sheltered workshops.

The results of the analysis confirm the established research hypothesis that social aspects in service tenders are still not widely used. It should be added that thanks to the study and the analysis of the literature on the subject, the assumed goal of verifying the scope of application of social aspects in tenders was achieved. In addition, the publication indicates the possibility of using internal auditing to evaluate the procurement process.

It is worth adding that the selection for the study of tenders for services was due to the direct involvement of the employees of the successful contractor in their implementation. This issue is of great importance. Social aspects in the assumption should increase the chances of excluded people to integrate into society and in finding their way in the labor market. Most often, social aspects were used in the analyzed service tender notices, specifying the requirement that the contractor hire employees on the basis of an employment contract. Public entities occasionally used in tenders a criterion limiting the catalog of entities eligible to participate in the tender to social cooperatives and entities employing people with disabilities. Activities in this area are very important because they enable the implementation of the principles of sustainable development. In general, it should be recognized that the introduction of social aspects in tenders is an important area of Poland's practical implementation of Agenda 2030.

A serious challenge for the public procurement system in EU countries, including Poland, is the lack of uniform legal regulations requiring the application of social criteria. Currently, legal acts do not explicitly require the application of social clauses in tenders. It is therefore necessary for legislative changes to be made at EU level to introduce the requirement to apply social clauses in every tender.

In conclusion, the research results and literature review presented in the publication showed that social aspects have been implemented in the Polish public procurement system to a limited extent. Public authorities should strive for a wider application of these aspects in tenders, especially with regard to services. In addition, the publication highlights the role of independent internal auditing in assessing the application of social clauses in public procurement. Auditors evaluating specific tenders can verify the extent to which specific social aspects are applied in them. In addition, internal auditors can bring to the attention of the management of a public finance sector entity that the application of social aspects is needed. However, this requires appropriate training of internal auditors in sustainable public procurement.

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QUANTITATIVE EASING AND CREDIT SUPPLY: 13 DEVELOPED ECONOMIES SIMULATED

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Purpose: This paper investigates how quantitative easing (QE) affects credit supply in advanced economies and whether the strength and direction of this impact vary across countries. It aims to identify the extent of heterogeneity in the credit channel of monetary transmission and determine under which structural and institutional conditions QE effectively stimulates credit creation.

Design/methodology/approach: The study uses quarterly BIS data for 13 advanced economies from 2008–2024. It applies the Local Projections method (Jordà, 2005) to estimate impulse response functions of credit to QE shocks, measured by changes in central bank balance sheets. The model includes country fixed effects and lagged endogenous variables to capture heterogeneity and dynamic adjustment. The analysis focuses on cross-country differences in the transmission of unconventional monetary policy.

Findings: Results reveal three clusters of credit responses to QE: (i) strong positive effects in Australia, the Euro area, New Zealand, the UK, and the US; (ii) weak but positive effects in Canada, Korea, Norway, and Poland; and (iii) weak and negative effects in Denmark, Japan, Sweden, and Switzerland. These outcomes indicate that QE supports credit growth only when supported by favorable financial and institutional environments. The findings confirm that QE's impact is heterogeneous and context-dependent rather than uniform across economies.

Research limitations/implications: A key limitation relates to lag selection in dynamic models, which may influence impulse response precision. Future studies should apply formal information criteria (AIC, BIC, HQC) and consider bank-level datasets or alternative transmission channels such as asset prices or exchange rates.

Practical implications: Liquidity injections alone are insufficient to ensure credit expansion. Policymakers should complement QE with measures that enhance bank profitability, reduce risk constraints, and stimulate loan demand. In flexible financial systems, QE can boost lending and investment, while in more rigid systems its effects remain limited.

Social implications: By clarifying how QE shapes credit creation, the study helps explain how monetary policy contributes to recovery, employment, and financial stability. Weak credit responses may restrict the broader social benefits of expansionary policies.

Originality/value: This is among the first comparative studies of QE's credit effects across 13 economies within a unified empirical framework. It documents substantial cross-country

heterogeneity and offers methodological guidance for future research on unconventional monetary policy.

Keywords: quantitative easing; credit supply; central bank; monetary policy.

Category: Research paper.

1. Introduction

Quantitative easing (QE) represents an unconventional monetary policy instrument employed by central banks to stimulate the economy through large-scale asset purchases and the injection of liquidity into the banking system. Following the global financial crisis of 2008, QE became a key component of monetary policy frameworks in the United States, the United Kingdom, the Euro area, and Japan. Empirical research shows that QE effectively increases commercial banks' reserves and lowers government bond yields, yet its transmission to bank lending remains complex and context-dependent, influenced by banks' portfolio structures, regulatory environments, and the transmission channels of monetary policy (Fatouh, 2016; Cecioni, Ferrero, Secchi, 2011).

In several cases, an increase in credit supply has been observed, particularly among banks heavily exposed to the assets purchased under QE. However, aggregate lending growth often remains moderate relative to the rise in reserves (Wang, 2023; Li, 2024). QE operates mainly through three channels - the "portfolio balance", "signaling", and "liquidity" channels (Yip, 2025). Asset purchases expand banks' reserves, reduce bond yields, and encourage a shift toward riskier or higher-yielding assets, which may in turn stimulate new lending (Li, 2024). The strength of these effects, however, depends on the structure of domestic financial systems and market conditions.

Studies for the United States, the United Kingdom, the Euro area, and Japan suggest that QE consistently increases banking system liquidity but that the response of lending is frequently limited or delayed (Papadamou, Siriopoulos, Kyriazis, 2020). In the U.S., the strongest credit growth was recorded among banks holding large volumes of mortgage-backed securities (MBS), with lending expanding by approximately 2-4% (Li, 2024). By contrast, Japan's approach emphasized long-term credit expansion, while the U.S. and U.K. focused primarily on rapid balance sheet expansion by central banks (Zeng, 2024; Rahman, Hutagaol, 2023).

The effectiveness of the credit channel is often constrained by structural factors such as low bank profitability, macroprudential regulations, or subdued loan demand (Papadamou et al., 2020). In some sectors, QE effects on credit proved short-lived, with banks more inclined to adjust their risk exposure than to increase loan volumes (Zhang, Liu, Liu, 2019). Cross-country differences in QE outcomes are therefore substantial, shaped by institutional structures, asset composition, and the regulatory context (Berger, Molyneux, Wilson, 2020; Li, 2024; Papadamou et al., 2020). In certain economies, QE has also been linked to rising financial risk-

taking and asset price bubbles (Djatche, 2021; Li, 2024; Carbó-Valverde, Cuadros-Solas, Rodríguez-Fernández, 2021; Albertazzi et al., 2020).

Overall, evidence suggests that QE's impact on bank credit is heterogeneous and generally moderate, largely conditioned by the financial structure and risk appetite of the banking sector (Papadamou et al., 2020).

This growing body of literature highlights both the potential and the limitations of QE as a tool for stimulating credit creation. Yet, despite extensive empirical evidence from the U.S. and the U.K., the specific mechanisms through which excess liquidity translates—or fails to translate—into new lending remain debated, particularly within the euro area context. Recent studies have therefore sought to identify the structural conditions under which QE may paradoxically weaken rather than strengthen the credit channel.

Stempel et al. (2024) argue that under conditions of very high reserve liquidity, quantitative easing (QE) can have the opposite effect: excess banks experience an increase in balance sheet costs associated with holding deposits, which reduces their willingness to lend. This mechanism has not yet been empirically confirmed in the eurozone context. The study uses a SVAR model with sign and zero restrictions to identify excess liquidity shocks in the Eurosystem banking system. This shock is defined as an exogenous increase in excess reserves resulting from QE measures, in the absence of an immediate response in output and inflation.

The authors then use Local Projections to assess the impact of such shocks on the dynamics of MFI loans to non-financial corporations (NFCs) in individual countries. The results reveal significant heterogeneity:

1. In countries with high liquidity (Germany, France, the Netherlands), QE causes a decline in lending (e.g., to -2.5% in the Netherlands).
2. In countries with low liquidity (Italy, Spain, Portugal), the effects are zero or positive (e.g., +1% in Portugal).

The study by Serranito et al. (2023) makes a significant contribution to the literature on the effectiveness of QE in the euro area through the bank lending channel. The authors focus on the structural nature of credit, distinguishing between financing the real economy and non-productive loans (mortgage, consumer, and financial institutions). The study hypothesizes that excess bank reserves do not translate into an increase in productive credit but rather support the financing of speculative assets. The authors introduce a division of credit into:

1. Productive: loans to non-financial corporations (real economy).
2. Non-productive: loans to mortgages, consumer, and financial institutions.

Local Projections and their smoothed versions were used, enabling the direct estimation of impulse response functions (IRFs) for credit and macroeconomic variables. The results presented by Serranito et al. show that:

1. Productive credit: QE triggers a negative response - banks restrict financing of the real economy.
2. Non-productive credit: a clearly positive response - increased financing of real estate, consumption, and the financial sector.
3. Real estate market: a strong and significant price increase, indicating the formation of price bubbles.
4. Industrial production and core inflation: no significant stimulus - QE does not significantly affect real economic activity or inflationary pressures.

The results are consistent across different methods of identifying QE shocks and across different indicators of excess liquidity, confirming their robustness.

Local Projections are effective in QE studies because they allow for direct estimation of the impulsive responses of variables to shocks, without requiring a full VAR specification. The method is robust to parameter instability and handles heterogeneous effects across countries or loan types well. Furthermore, they work with various shock identification methods and enable stable estimations, particularly in the smoothed version.

Local Projections, however, are not the only simulation method used to study QE. Silva et al.'s (2021) paper examines the effectiveness of conventional and unconventional monetary policy in an agent-based model that incorporates the interbank market and the central bank. The model includes households, consumer and capital firms, commercial banks, and the central bank, operating in the labor, consumption, capital, and credit markets. Conventional policy is simulated by the Taylor rule—a formula that determines the central bank interest rate based on deviations of inflation and output from their target levels. Unconventional policy is simulated by quantitative easing (QE) with threshold intervention at the unemployment rate.

Validation of the model against US data (1955-2015) demonstrated realistic GDP and interbank market dynamics and the ability to reproduce crises at unemployment rates greater than or equal to 15%. Experiments have shown that QE significantly reduces the number and intensity of crises compared to Taylor rules. Early intervention (unemployment threshold of 8%) eliminates crises and also stabilizes the labor market (lower standard deviation of the unemployment rate and lower kurtosis). The model does not account for nominal wage adjustments, so the impact of QE on inflation remains undetermined.

The conclusions indicate that agent-based macroeconomic models allow for the comparison of the effectiveness of various monetary policy instruments, and that QE is more effective in stabilizing the business cycle than the conventional Taylor rule.

Similarly, other methods can be applied to loans. Grimaldi & Kapoor (2023) analyzes the impact of the US Federal Reserve's quantitative easing (QE) policy on commercial bank lending, with particular emphasis on the heterogeneity of financial institutions. The authors demonstrate that QE's effects are not uniform but depend on the type of assets purchased (MBS vs. Treasury bonds) and on banks' internal characteristics, such as liquidity and capital

resilience. This study fills a gap in the literature, which has previously focused primarily on the macroeconomic effects of QE and neglected its implications for loan volume.

The authors describe in detail the three main phases of the Fed's QE program. The first wave, QE1 (2008-2010), included the purchase of \$1.25 trillion in MBS and \$475 billion in Treasury and agency securities, increasing the Fed's share of the MBS market to approximately 25%. QE2 (2010-2011) purchased \$600 billion in Treasury bonds and \$178 billion in reinvestments. The final wave, QE3 (2012-2014), was an open-ended program, consisting of monthly purchases of \$40 billion in MBS and \$45 billion in Treasury bonds, totaling \$1.613 trillion in assets.

The empirical analysis covers 7124 bank holding companies (BHCs) from 2006Q1 to 2014Q4, using quarterly FR-Y9C financial data. Banks' exposure to QE was measured as the share of MBS or Treasury bonds in assets before the program began. Banks in the top 25% of the distribution were designated as the treatment group, and the bottom 25% as the control group. Institutional heterogeneity was accounted for through measures of liquidity, defined as the share of cash and overnight deposits in assets, and capital resilience, expressed as the Tier 1 ratio to risk-weighted assets. The analysis utilized a difference-in-differences (DiD) model with interactions accounting for QE exposure, treatment group status, and bank characteristics, with the effects lagged by four quarters. Bank size, loan-to-deposit ratio, profitability, and bank and state-quarter fixed effects were also controlled.

The study results show that the impact of QE on bank lending depended on the type of assets purchased and the bank's condition. Banks well-endowed with liquidity and capital reduced lending after purchasing MBS but increased it after purchasing Treasury bonds. Weaker banks responded in the opposite way. The effects were uneven across banks and were strongest during QE3, and the results remained stable across bank groupings. The authors emphasize that bank heterogeneity is crucial for understanding how QE affects the real economy through the credit channel. From a monetary policy perspective, this means that quantitative easing programs should consider both the type of assets purchased and the diverse health of banks to effectively stimulate the economy. Nonlinear and differently oriented bank responses may explain the contradictory findings in the existing literature on the impact of QE on lending.

2. Methods

The primary objective of this study is to assess the impact of quantitative easing (QE) on the supply of credit across advanced economies and to identify cross-country heterogeneity in the strength and direction of this relationship. This objective is consistent with recent research that shows that monetary-policy shocks of the same size generate very different real and financial responses across countries, largely because of institutional and financial-market

characteristics (Pica, 2023). By employing the Local Projections (LP) method based on BIS quarterly data for the period 2008-2024, the paper seeks to evaluate how central bank balance sheet expansions translate into credit growth under different institutional and financial conditions.

Based on previous findings (Cecioni, Ferrero, Secchi, 2011; Papadamou, Siriopoulos, Kyriazis, 2020; Li, 2024), and on more recent evidence of heterogeneous QE effects at the level of banks and mortgage markets (Grimaldi, Kapoor, 2023; Hertel et al., 2022), the study formulates the following hypotheses:

- H1: Quantitative easing (QE) exerts a positive effect on credit supply in advanced economies.
- H2: The magnitude of the credit response to QE is heterogeneous across countries, reflecting structural and institutional differences in banking systems (cf. Pica, 2023; Brissimis, Papafilis, 2022).
- H3: In economies with persistent low interest rates and structural constraints (e.g., Japan, Sweden, Switzerland), the credit response to QE is weaker or insignificant.

These hypotheses allow the study to test not only the average effectiveness of QE in stimulating credit, but also the cross-country variation in its transmission mechanisms.

This paper collects quarterly data from 2008-2024 for 13 countries or regions: Australia, Canada, Denmark, the Eurozone, Japan, South Korea, New Zealand, Norway, Poland, Sweden, Switzerland, the UK, and the USA. These are the major developed economies and those important from a monetary policy perspective. Four variables were created:

- *qe* – the share of central bank assets in GDP. This variable is measured as the ratio of the central bank's balance sheet measured in domestic currency (incl. conversion to current currency made using a fixed parity or market exchange rate).
- *credit* – the share of credit from all sectors to the non-financial private sector at market value in GDP.
- *qe_qoq* – the quarterly rate of change in the share of central bank assets in GDP; this value approximates the relative (percentage) change from quarter to quarter. Calculated as the difference of natural logarithms:

$$qe\_qoq_t = \ln(qe_t) - \ln(qe_{t-1})$$

- *credit_qoq* – quarterly rate of change in the share of private credit in GDP, calculated analogously:

$$credit\_qoq_t = \ln(credit_t) - \ln(credit_{t-1})$$

We chose this method of calculating quarterly changes because financial and macroeconomic data are often heteroscedastic. Logarithmic transformation reduces this problem by “flattening” the data and making them more comparable over time. Furthermore, changes expressed in logarithms are additive over time, meaning that successive increases can be added together, and the result corresponds to cumulative growth. Logarithmic differences are commonly used in macroeconomic and financial research, particularly in analyzing the

dynamics of variables such as GDP, asset prices, and credit, and they are also standard in recent QE studies for the euro area and Poland (Pica, 2023; Hertel et al., 2022). As a result, the obtained results are consistent with conventions adopted in the literature.

For the purposes of the empirical analysis, we used internationally comparable statistical data from the Bank for International Settlements (BIS). The BIS maintains unified macroeconomic and financial databases, which enable comparisons and eliminate the problem of inconsistent definitions used by individual countries. The *qe* variable was taken from the Central Bank Total Assets (WS_CBTA) dataset, while the credit variable comes from the Credit to the Non-Financial Sector (WS_TC) dataset. Expressing this variable as a percentage of GDP allows us to assess the scale of private debt in the economy and compare it over time and across countries. This choice mirrors the data strategy in multi-country studies of monetary-policy heterogeneity, where cross-country comparability and uniform definitions are crucial (Pica, 2023).

Normality tests such as Shapiro–Wilk, Jarque–Bera, Kolmogorov–Smirnov and Anderson–Darling were performed to check whether the data are normally distributed. The Kruskal–Wallis test was used as a nonparametric statistical test to detect seasonality. To assess the validity of the classical regression model’s assumptions, the Breusch–Pagan test was conducted, which detects heteroscedasticity, i.e. variation in the variance of the error term. Next, the Durbin–Watson test was performed to test for autocorrelation of the error terms, i.e. the dependence of error terms between subsequent observations. Additionally, the Ramsey RESET test was used to verify the model’s specification and identify any omitted nonlinearities or significant variables

Given the following analysis, the Local Projections method (Jordà, 2005) is used in this paper. It is particularly suitable in this case because it does not require the assumption of normality in the distribution of residuals or explanatory variables and is resistant to heteroscedasticity. Crucially, recent econometric work has shown that, under fairly general conditions, LPs and VARs deliver the same impulse responses, so choosing LPs here is a matter of flexibility and robustness rather than a departure from the mainstream identification toolbox (Plagborg-Møller, Wolf, 2021). This method allows us to examine how a given variable responds to a shock in subsequent periods and to let the responses differ across countries, which is essential in a context where earlier studies have documented heterogeneous and sometimes even non-linear lending reactions to QE depending on bank liquidity and market structure (Grimaldi, Kapoor, 2023; Brissimis, Papafilis, 2022). Instead of building a single complex model describing the entire dynamics of the economy, as is the case with VAR models, Local Projections involve estimating separate regression equations for each time horizon.

3. Results

Shapiro-Wilk, Jarque-Bera, Kolmogorov-Smirnov and Anderson-Darling tests performed for the studied variables showed categorical rejection of the normal distribution hypothesis. The Kruskal-Wallis' tests the null hypothesis that the medians for all quarters of the year are equal, implying no seasonal differences. However, the results indicate no statistically significant seasonality in all countries studied. Tables with values are provided in the Appendix.

After including all data from all countries, the correlation matrix shows that the data is uncorrelated and statistically insignificant. The only statistically significant, weak positive correlation is between studied variables *qe* and *credit* and their quarterly changes. This property indicates the need to include country fixed effects and suggests that simple linear models may be inadequate.

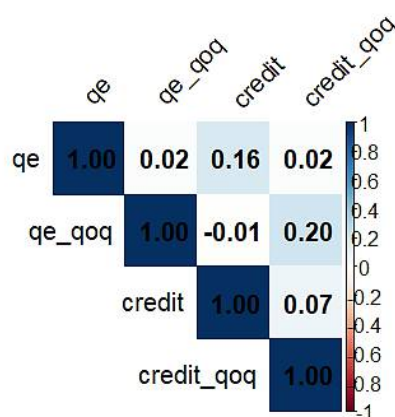


Figure 1. The correlation matrix.

Source: Own work.

The correlation between quarterly changes provides limited analytical value when assessing the impact of quantitative easing on credit - changes are typically irregular, and it takes time for one to influence the other.

Empirical analysis indicates significant variation in the relationship between quantitative easing (QE) and credit growth across countries. In some economies (Switzerland, Sweden, Canada, Norway, and Japan), we observe complementarity - a strong positive correlation, suggesting that the expansion of the central bank's balance sheet supported credit growth. In other countries, particularly Korea and the United Kingdom, a substitution effect is visible, where an increase in QE was associated with a reduction in credit growth. For Anglo-Saxon economies such as the United States, Australia, and New Zealand, this relationship is negative but relatively weaker. In Poland, on the other hand, no statistically significant correlation between the two processes was found. These results emphasize the heterogeneity of monetary policy transmission - the impact of QE on the credit sector is strongly determined by local institutional and structural conditions.

Therefore, we conducted a diagnostic analysis of regression models (in which *qe* explains *credit*) including country fixed effects - we allow a different intercept and slope for each country. The diagnostics also reveal significant violations of classical assumptions. The Breusch-Pagan test indicates the presence of heteroscedasticity - the variability of errors in the statistical model is not constant. The Durbin-Watson test indicates, suggesting strong positive autocorrelation of the residuals - the error from one period is related to the error from the next period, which violates the assumption of classical regression models. The RESET test did not detect any functional specification issues, which means that the linear Local Projections structure mentioned below is adequate. The regression models and test results are in the Appendix.

A set of Local Projections was estimated separately for each selected country. The shock variable in the model was the quarterly change in central bank assets (*qe_qoq*), while the response variable was the quarterly change in credit supply (*credit_qoq*). The model included two lags of endogenous variables - if we analyze the quarterly change in credit supply, we can assume that its current level depends not only on the current shock but also on how credit supply changed in the two preceding quarters. The lag of two quarters was chosen heuristically. This is intended to better capture the dynamics and prevent attribution of effects to the shock that result solely from inertia or trends in credit supply itself. Confidence intervals were estimated at the 95% level. Impulse responses were analyzed for a horizon of up to eight quarters after the shock, with the shock defined as an increase equal to one standard deviation in the *qe_qoq* variable. The results are presented in impulse response (IRF) plots and in tables in the Appendix, which include both point values and confidence bounds.

3.1. Australia, Euro Zone, New Zealand, United Kingdom, United States

In countries such as Australia, the Eurozone, New Zealand, the United Kingdom, and the United States, the credit response to a positive shock to the central bank's balance sheet is significantly positive (approximately +3.04%, +6.54%, +6.29%, +7.29%, and +4.33%, respectively), indicating the effectiveness of the credit channel of monetary policy.

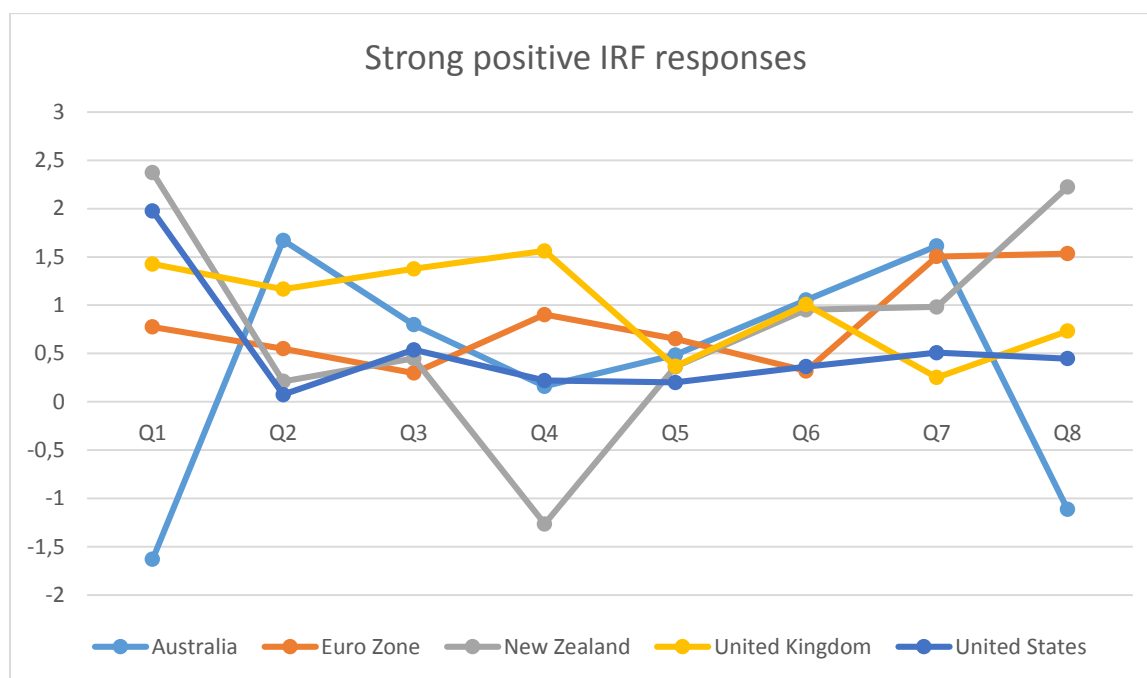


Figure 2. The line chart with IRF from 5 countries with strong positive responses.

Source: Own work.

Cumulative IRF values exceeding at least 3 percentage points may suggest that an increase in central bank assets leads to a significant expansion in the supply of credit to the private sector. This means that in these economies, quantitative easing effectively lowers financing costs, increases liquidity in the banking system, and stimulates lending. The monetary policy transmission mechanism operates in a classic manner: increased liquidity translates into easier access to credit for businesses and households, which supports economic growth. A common feature of this group of countries is highly developed financial markets, a dominant role of the private sector in financing investment, and flexible financial systems that enable the efficient transmission of monetary impulses from the central bank's balance sheet to the real economy.

3.2. Canada, Korea, Norway, Poland

In the group comprising Canada, Korea, Norway, and Poland, the credit response to central bank balance sheet expansion is positive (approximately +1.79%, +0.70%, +1.71% and +0.70%, respectively), but relatively weak and unstable.

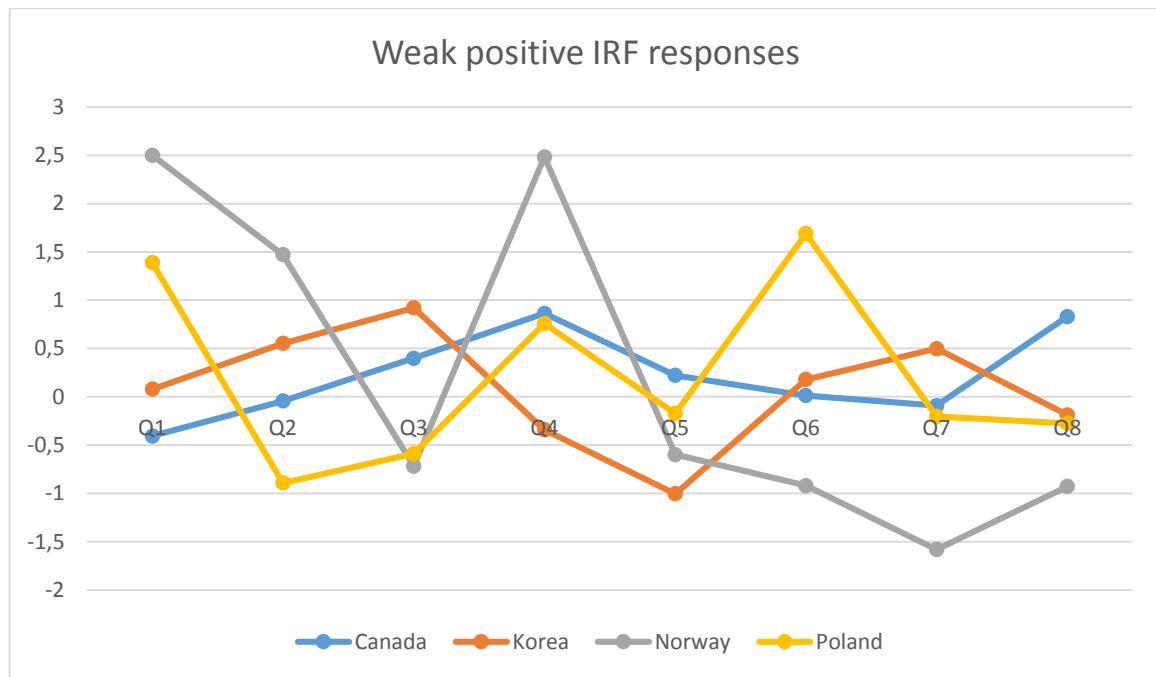


Figure 3. The line chart with IRF from 4 countries with weak positive responses.

Source: Own work.

Cumulative IRF values ranging from 0 to 3 indicate that the increase in central bank assets translates into a moderate credit expansion, but this effect is time-limited or occurs with a lag. This may indicate that in these economies, part of the monetary impulse is absorbed by other transmission channels, such as the exchange rate or asset prices, reducing the direct impact on credit supply. Additionally, a weaker response may result from limited demand for financing, a cautious banking sector stance, or existing capital restrictions that limit the scope for increased lending. In these countries, quantitative easing also plays a smaller role within monetary policy, making its impact on the credit sector more marginal compared to economies where this instrument is a key element of monetary transmission.

3.3. Denmark, Japan, Sweden, Switzerland

In the group comprising Denmark, Japan, Sweden, and Switzerland, the credit response to central bank balance sheet expansion is negative or close to zero (approximately -2.85%, -2.67%, -0.50% and -0.33%, respectively), indicating the ineffectiveness of the credit channel in transmitting monetary policy impulses.

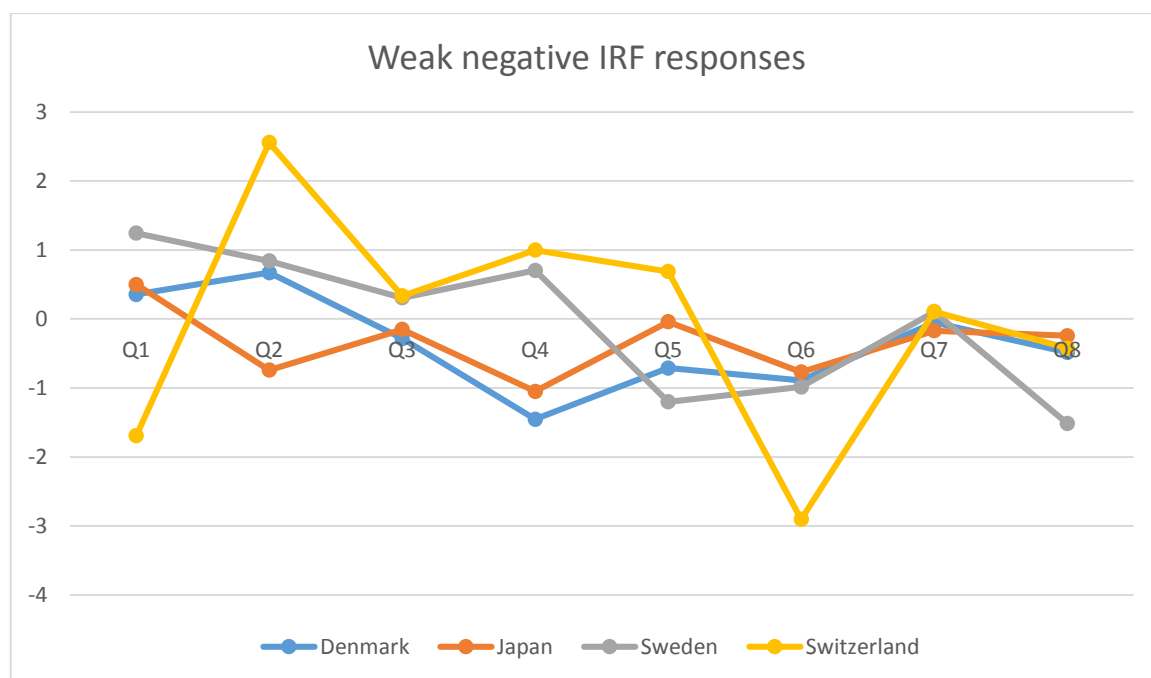


Figure 4. The line chart with IRF from 4 countries with weak negative responses.

Source: Own work.

In these economies, an increase in central bank assets does not lead to an increase in credit supply, and in some cases may even restrict it. Such results suggest the existence of structural barriers to the functioning of the financial sector, such as excess bank liquidity, persistent deflationary expectations, or a low propensity to take credit risk, particularly visible in the case of Japan. Furthermore, the limited credit response may result from a shift in monetary policy transmission toward alternative channels, particularly the exchange rate, which in small, open economies often plays a more important role than the credit channel. In some cases, restrictive financial regulations and a conservative stance of the banking sector may also play a significant role, limiting the ability or willingness of financial institutions to expand credit even in conditions of increased monetary liquidity.

4. Discussion

The results confirm that the effects of quantitative easing (QE) on credit supply are heterogeneous across developed economies, reflecting differences in financial structures, transmission channels, and the institutional environment. In countries such as Australia, the euro area, New Zealand, the United Kingdom, and the United States, QE effectively supported credit expansion, suggesting that abundant liquidity and flexible financial intermediation enabled a robust credit channel. These findings are consistent with Pica (2023), who documents that economies with deep capital markets and diversified banking sectors

experience stronger balance sheet and credit responses to monetary expansion. Similarly, Grimaldi and Kapoor (2023) find that in jurisdictions with well-developed financial markets, QE stimulates bank lending primarily through the balance sheet and risk-taking channels, amplifying credit supply to the private sector.

By contrast, in Canada, Korea, Norway, and Poland, the response of credit to QE shocks was positive but modest and often short-lived. This result is in line with Brissimis and Papafilis (2022), who argue that in smaller, bank-dominated systems, QE effects may be partially offset by low loan demand and heightened macroprudential discipline. Hertel et al. (2022) similarly report that in Poland, the domestic QE program increased liquidity and lowered yields but did not translate proportionally into credit expansion, underscoring the role of structural constraints and risk aversion within the banking sector. In these economies, liquidity injections may have been partially absorbed through exchange rate adjustments or sovereign debt purchases rather than through credit creation.

In Denmark, Japan, Sweden, and Switzerland, the impact of QE on credit was neutral or even negative, which corroborates findings by Shah et al. (2025), who show that persistent low interest rates and deflationary expectations weaken banks' risk appetite, causing QE to operate more through asset-price and portfolio channels than through the credit channel. These results highlight that in environments characterized by long-lasting monetary accommodation and compressed margins, additional liquidity may contribute to asset inflation rather than real-sector lending.

From a methodological standpoint, the study demonstrates the usefulness of the Local Projections (LP) framework in analyzing heterogeneous, country-specific responses to monetary shocks. The results of Löf and Nyberg (2024) reinforce this approach, showing that LP methods are more flexible and less susceptible to misspecification than traditional VAR models, especially when responses vary across horizons or institutional contexts. This flexibility is crucial in multi-country analyses, as also emphasized by Plagborg-Møller and Wolf (2021), who show that under standard identification conditions, LPs and VARs estimate the same population impulse responses. Consequently, the LP approach used in this study should be viewed as a robust and transparent method for cross-country comparisons of QE effectiveness.

Moreover, the discussion highlights the need to integrate methodological rigor with economic interpretation. Future research may benefit from combining LP estimation with variable selection techniques such as LASSO or information-criterion-based lag optimization (AIC, BIC, HQC), as suggested by Löf and Nyberg (2024), to enhance model precision. Such improvements would make it possible to disentangle the distinct contributions of institutional and macro-financial factors to the heterogeneous outcomes of QE policies.

Overall, the findings emphasize that QE's effectiveness in stimulating credit depends not only on the magnitude of asset purchases but also on the structural and behavioral features of the banking system. Liquidity injections alone are insufficient to ensure credit expansion;

complementary measures addressing bank profitability, capital requirements, and loan demand are essential to reactivate the credit channel of monetary policy. The empirical evidence confirms H1, demonstrating that QE generally exerts a positive influence on credit supply across advanced economies. At the same time, the significant cross-country variation in responses supports H2, indicating that QE transmission is conditioned by institutional and structural characteristics. Finally, the weak or negative responses observed in Japan, Sweden, Switzerland, and Denmark are consistent with H3, suggesting that persistent low interest rates and structural constraints may substantially weaken the credit channel of monetary policy.

The results confirm that the effects of quantitative easing on credit supply are heterogeneous across developed economies, reflecting differences in financial structures, transmission channels, and the institutional environment. In countries such as Australia, the euro area, New Zealand, the United Kingdom, and the United States, QE effectively supported credit

5. Summary

This study assessed the impact of quantitative easing (QE) on credit supply across advanced economies and tested the hypothesis that this relationship is heterogeneous and shaped by country-specific structural conditions. Using BIS quarterly data for 13 developed countries (2008-2024) and the Local Projections (LP) framework (Jordà, 2005), the analysis identified how changes in central bank balance sheets affect credit dynamics. The results confirmed that QE generally supports credit expansion, but the magnitude and direction of the response vary considerably across economies. Three clusters of effects were identified: strong positive (Australia, euro area, New Zealand, United Kingdom, United States), weak positive (Canada, Korea, Norway, Poland), and weak or negative (Denmark, Japan, Sweden, Switzerland).

These findings are consistent with a broad body of evidence emphasizing the conditional effectiveness of QE. Studies such as Pica (2023) and Grimaldi and Kapoor (2023) show that QE is most effective in economies with deep and diversified financial markets, while Brissimis and Papafilis (2022) and Hertel et al. (2022) demonstrate that in smaller or more regulated systems, liquidity expansions often fail to produce proportional credit growth. Likewise, Shah et al. (2025) highlight that in low-rate environments, the credit channel weakens in favor of asset-price and portfolio effects. The observed heterogeneity therefore supports the view that QE's transmission is not uniform and that its success depends on institutional and market-specific features (Berger, Molyneux, Wilson, 2020).

From a methodological perspective, this study contributes to the growing empirical literature that applies the LP approach to assess monetary-policy transmission (Plagborg-Møller, Wolf, 2021; Löf, Nyberg, 2024). By explicitly modeling heterogeneous impulse responses across countries, the LP framework offers a flexible and transparent alternative to

traditional VAR models. Future research should apply formal information criteria (AIC, BIC, HQC) and regularization techniques to refine lag selection and improve the robustness of inference.

Overall, the evidence confirms that while QE can foster credit growth under favorable structural and institutional conditions, its macroeconomic effectiveness remains context-dependent. Effective credit transmission requires complementary macroprudential, fiscal, and regulatory policies that strengthen the profitability and lending capacity of banks.

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Appendix

The appendix contains all the values of the selected tests and the exact simulation results.

Table 1.

Normality tests' approximate values for variables

<i>qe</i>	Shapiro-Wilk	Jarque-Bera	Kolmogorov-Smirnov	Anderson-Darling
Test value	$W = 0.685$	$JB = 1575.089$	$D = 0.269$	$A = 99.762$
p-value	$1.3 * 10^{-37}$	0.000	$7.2 * 10^{-56}$	$3.7 * 10^{-24}$
<i>credit</i>	Shapiro-Wilk	Jarque-Bera	Kolmogorov-Smirnov	Anderson-Darling
Test value	$W = 0.941$	$JB = 34.345$	$D = 0.123$	$A = 16.432$
p-value	$3.3 * 10^{-18}$	$3.5 * 10^{-8}$	$5.1 * 10^{-12}$	$3.7 * 10^{-24}$
<i>qe_qoq</i>	Shapiro-Wilk	Jarque-Bera	Kolmogorov-Smirnov	Anderson-Darling
Test value	$W = 0.749$	$JB = 20342.92$	$D = 0.161$	$A = 47.111$
p-value	$2.5 * 10^{-34}$	0.000	$5.5 * 10^{-20}$	$3.7 * 10^{-24}$
<i>credit_qoq</i>	Shapiro-Wilk	Jarque-Bera	Kolmogorov-Smirnov	Anderson-Darling
Test value	$W = 0.524$	$JB = 864280.2$	$D = 0.169$	$A = 61.624$
p-value	$3.1 * 10^{-43}$	0.000	$4.4 * 10^{-22}$	$3.7 * 10^{-24}$

Table 2.

Correlation coefficients' approximate values between qe and credit

Country	Correlation coefficient	p-value
Australia	-0.27218	0.02474
Canada	0.70279	$2.381 * 10^{-11}$
Denmark	0.52892	$3.538 * 10^{-6}$
Euro Zone	0.47949	$3.519 * 10^{-5}$
Japan	0.61122	$3.095 * 10^{-8}$
Korea	-0.62554	$1.175 * 10^{-8}$
New Zealand	-0.37354	0.00170
Norway	0.64367	$3.209 * 10^{-9}$
Poland	-0.15244	0.21461
Sweden	0.83294	$1.276 * 10^{-18}$
Switzerland	0.92339	$3.793 * 10^{-29}$
United Kingdom	-0.54382	$1.645 * 10^{-6}$
United States	-0.35099	0.00334

Table 3.

Kruskal-Wallis' test for seasonality approximate results

Country	<i>qe</i> p-value	<i>credit</i> p-value
Australia	0.89998	0.99684
Canada	0.89240	0.92142
Denmark	0.99503	0.98667
Euro Zone	0.96085	0.94342
Japan	0.99058	0.95452
Korea	0.50243	0.95981
New Zealand	0.86987	0.97911
Norway	0.95812	0.99269
Poland	0.97074	0.99886

Sweden	0.99132	0.99961
Switzerland	0.99853	0.99780
United Kingdom	0.97423	0.99252
United States	0.99891	0.97856

Table 4.*Regression model without country effects*

Model				
$credit = 0.275 * qe + 179.380$				
Breusch-Pagan	Durbin-Watson	Ramsey RESET	F statistic	Model fit
$BP = 0.144$	$DW = 0.040$	$F = 17.442$	$F = 24.790$	$R^2 = 0.0273$
$p = 0.070$	$p = 9.8 * 10^{-188}$	$p = 3.7 * 10^{-8}$	$p = 7.7 * 10^{-7}$	$R^2_{adj} = 0.0262$

Table 5.*Regression models with country effects (different intercepts)*

Country	Model			
Australia	$credit = 0.339 * qe + 180.358$			
Canada	$credit = 0.339 * qe + 200.024$			
Denmark	$credit = 0.339 * qe + 241.404$			
Euro Zone	$credit = 0.339 * qe + 156.279$			
Japan	$credit = 0.339 * qe + 141.390$			
Korea	$credit = 0.339 * qe + 169.909$			
New Zealand	$credit = 0.339 * qe + 171.252$			
Norway	$credit = 0.339 * qe + 227.200$			
Poland	$credit = 0.339 * qe + 66.928$			
Sweden	$credit = 0.339 * qe + 234.659$			
Switzerland	$credit = 0.339 * qe + 212.224$			
United Kingdom	$credit = 0.339 * qe + 156.262$			
United States	$credit = 0.339 * qe + 148.501$			
Breusch-Pagan	Durbin-Watson	Ramsey RESET	F statistic	Model fit
$BP = 114.090$	$DW = 0.134$	$F = 85.489$	$F = 758.7$	$R^2 = 0.9189$
$p = 2.9 * 10^{-18}$	$p = 1.9 * 10^{-175}$	$p = 1.3 * 10^{-34}$	$p = 2.2 * 10^{-16}$	$R^2_{adj} = 0.9177$

Table 6.*Regression models with country effects (different intercepts and slopes)*

Country	Model			
Australia	$credit = -0.379 * qe + 189.052$			
Canada	$credit = 2.667 * qe + 181.744$			
Denmark	$credit = 1.953 * qe + 199.893$			
Euro Zone	$credit = 0.185 * qe + 161.790$			
Japan	$credit = 0.161 * qe + 154.935$			
Korea	$credit = -3.567 * qe + 277.063$			
New Zealand	$credit = -0.669 * qe + 186.001$			
Norway	$credit = 3.376 * qe + 175.370$			
Poland	$credit = -0.268 * qe + 81.104$			
Sweden	$credit = 2.277 * qe + 200.487$			
Switzerland	$credit = 0.652 * qe + 183.885$			
United Kingdom	$credit = -0.642 * qe + 181.604$			
United States	$credit = -0.348 * qe + 164.340$			
Breusch-Pagan	Durbin-Watson	Ramsey RESET	F statistic	Model fit
$BP = 136.524$	$DW = 0.270$	$F = 1.927$	$F = 678.6$	$R^2 = 0.9519$
$p = 2.5 * 10^{-17}$	$p = 2.5 * 10^{-156}$	$p = 0.146$	$p = 2.2 * 10^{-16}$	$R^2_{adj} = 0.9505$

Below, we present the results of the Local Projections simulations in the form of 13 tables, each representing the simulation values for the studied countries. Each country is provided with IRF values and confidence intervals (both multiplied by 100). Because the *credit_qoq* variable is defined as a difference in logarithms, the percentage values lose their multiplicative nature at the expense of their additive nature - to obtain the total change over the eight quarters, the IRF values must be summed. Confidence intervals for impulse response functions are computed based on the robust Newey-West standard errors, according to the following formula:

$$IRF_{bounds} = IRF \pm 1.96 * SE$$

Where *SE* is a standard error estimated using the Newey-West method. The coefficient 1.96 is the multiple that corresponds to a confidence level of 95%.

Table 7.

Local Projections approximate values for IRF and the confidence bounds for Australia

Australia results for Local Projections			
quarter	IRF	lower confidence bound	upper confidence bound
1	-1.6313333436837	-3.73080240037614	0.468135713008737
2	1.67199471099902	-0.843621715935673	4.18761113793371
3	0.798671277582065	-0.973284133832014	2.57062668899614
4	0.160685347704672	-2.02268428458448	2.34405497999383
5	0.484933830678326	-1.69361710889542	2.66348477025208
6	1.0540646528452	-1.14133553545997	3.24946484115037
7	1.61291842106082	-0.493409496202983	3.71924633832463
8	-1.11316120543722	-2.96041431513609	0.734091904261653
3.038773692		the total change over 8 quarters	

Table 8.

Local Projections approximate values for IRF and the confidence bounds for Canada

Canada results for Local Projections			
quarter	IRF	lower confidence bound	upper confidence bound
1	-0.406577289832882	-1.12235011369318	0.309195534027413
2	-0.0428283378552967	-0.647154443370598	0.561497767660005
3	0.398230490172663	-0.73823244572212	1.53469342606745
4	0.863053215543881	-0.22197855064604	1.9480849817338
5	0.221883749139986	-0.618765958318508	1.06253345659848
6	0.0133003591818196	-0.663326403086034	0.689927121449673
7	-0.091355534618081	-0.775695643839135	0.592984574602973
8	0.829918648524968	-0.166250088213239	1.82608738526318
1.7856253		the total change over 8 quarters	

Table 9.

Local Projections approximate values for IRF and the confidence bounds for Denmark

Denmark results for Local Projections			
quarter	IRF	lower confidence bound	upper confidence bound
1	0.355642107976317	-0.777895621154717	1.48917983710735
2	0.672584801021471	-1.5915497300509	2.93671933209384
3	-0.284802307163721	-1.76615501860816	1.19655040428072
4	-1.45429613536185	-2.48250138311308	-0.426090887610621
5	-0.710917004655285	-1.80774647531841	0.385912466007838
6	-0.891956432305372	-1.60904670580508	-0.174866158805661
7	-0.0529624578891486	-0.776861783330612	0.670936867552314

8	-0.484569191210895	-1.96881665078433	0.999678268362535
	-2.85127662	the total change over 8 quarters	

Table 10.

Local Projections approximate values for IRF and the confidence bounds for Euro Zone

Euro Zone results for Local Projections			
quarter	IRF	lower confidence bound	upper confidence bound
1	0.77466269703526	-0.726900678395825	2.27622607246635
2	0.550416797702441	-0.4600327575335	1.56086635293838
3	0.296956744895377	-1.09004510686676	1.68395859665752
4	0.903328245723587	-0.150695611665367	1.95735210311254
5	0.652736345561567	-0.643803663733398	1.94927635485653
6	0.319598749368802	-1.73581994209754	2.37501744083514
7	1.50463859778216	0.619775159867462	2.38950203569685
8	1.53408646493419	0.154926839491216	2.91324609037717
	6.536424643	the total change over 8 quarters	

Table 11.

Local Projections approximate values for IRF and the confidence bounds for Japan

Japan results for Local Projections			
quarter	IRF	lower confidence bound	upper confidence bound
1	0.498767116672489	-0.282202986284158	1.27973721962914
2	-0.742377568019966	-1.79539642619423	0.310641290154298
3	-0.151635052676141	-0.688135390617745	0.384865285265463
4	-1.04926761114311	-1.6461539567718	-0.452381265514414
5	-0.0410922316860797	-1.12807453363807	1.04589007026591
6	-0.769897850066623	-1.38690569941475	-0.152890000718492
7	-0.171323721783863	-0.706554098175656	0.363906654607931
8	-0.242073438266701	-0.828849942230684	0.344703065697283
	-2.668900357	the total change over 8 quarters	

Table 12.

Local Projections approximate values for IRF and the confidence bounds for Korea

Korea results for Local Projections			
quarter	IRF	lower confidence bound	upper confidence bound
1	0.079788449185785	-0.785203588274669	0.944780486646238
2	0.553740895249992	-0.277198744025885	1.38468053452587
3	0.920703550415181	-0.231568814839975	2.07297591567034
4	-0.341106169826532	-1.56249251952696	0.880280179873891
5	-1.00410473146196	-1.9472917975164	-0.0609176654075249
6	0.177937252995616	-0.347627665139333	0.703502171130566
7	0.497804466451399	-0.252921845173212	1.24853077807601
8	-0.187132658763125	-1.51549717092917	1.14123185340292
	0.697631054	the total change over 8 quarters	

Table 13.

Local Projections approximate values for IRF and the confidence bounds for New Zealand

New Zealand results for Local Projections			
quarter	IRF	lower confidence bound	upper confidence bound
1	2.37387436153867	-0.319929307948019	5.06767803102535
2	0.212148444894583	-1.5973258613795	2.02162275116866
3	0.448582360438585	-2.13927754240936	3.03644226328653
4	-1.2654748383961	-2.84299853317504	0.312048856382831
5	0.362882389166914	-1.91321512667399	2.63897990500782

6	0.952109202234919	-1.40607820154124	3.31029660601108
7	0.981857500602439	-1.66576121438298	3.62947621558785
8	2.22262429343323	0.211773130422047	4.23347545644442
6.288603714		the total change over 8 quarters	

Table 14.

Local Projections approximate values for IRF and the confidence bounds for Norway

Norway results for Local Projections			
quarter	IRF	lower confidence bound	upper confidence bound
1	2.5004948804087	-0.0555872651763042	5.0565770259937
2	1.47039484707476	-0.458900183462864	3.39968987761238
3	-0.718671244491555	-3.49270894872844	2.05536645974533
4	2.48387338658022	0.310206978193792	4.65753979496664
5	-0.598655208326965	-2.01459028823405	0.817279871580115
6	-0.920553042602299	-3.06929261157594	1.22818652637134
7	-1.58104844040807	-3.2979927620773	0.135895881261148
8	-0.928355111510678	-2.69170815633996	0.834997933318607
1.707480067		the total change over 8 quarters	

Table 15.

Local Projections approximate values for IRF and the confidence bounds for Poland

Poland results for Local Projections			
quarter	IRF	lower confidence bound	upper confidence bound
1	1.3878916009697	-0.113310085620752	2.88909328756015
2	-0.892846400778989	-2.49446189986113	0.708769098303153
3	-0.588315950562585	-1.74202257506234	0.565390673937167
4	0.758433321132173	-0.569336054190228	2.08620269645457
5	-0.172849763816462	-1.60682783178858	1.26112830415566
6	1.68918373289212	0.583798766779552	2.79456869900468
7	-0.204748168673073	-1.66209266015649	1.25259632281034
8	-0.275487345578896	-1.38232288858998	0.831348197432192
1.701261026		the total change over 8 quarters	

Table 16.

Local Projections approximate values for IRF and the confidence bounds for Sweden

Sweden results for Local Projections			
quarter	IRF	lower confidence bound	upper confidence bound
1	1.24372430729893	-1.23545542459871	3.72290403919656
2	0.841355411847128	-0.385724878541998	2.06843570223625
3	0.307218902837047	-1.2621433986332	1.87658120430729
4	0.703479977575907	-2.21728964390275	3.62424959905457
5	-1.20134681054419	-4.71526787446179	2.31257425337342
6	-0.984824284894103	-3.62622754374876	1.65657897396055
7	0.101661769728319	-1.38630599040763	1.58962952986426
8	-1.51305187354842	-3.05558517579199	0.0294814286951589
-0.5017826		the total change over 8 quarters	

Table 17.*Local Projections approximate values for IRF and the confidence bounds for Switzerland*

Switzerland results for Local Projections			
quarter	IRF	lower confidence bound	upper confidence bound
1	-1.69247369351655	-3.47628013240276	0.0913327453696516
2	2.55817937657374	-0.619373420054373	5.73573217320185
3	0.334563673632464	-2.17178980796291	2.84091715522784
4	0.998941203534369	-1.13252356155113	3.13040596861987
5	0.688317293786464	-1.33879750994121	2.71543209751414
6	-2.90396101598065	-6.21108082427919	0.403158792317884
7	0.107190063710399	-1.60486033112113	1.81924045854193
8	-0.424667313150388	-2.04731990489451	1.19798527859373
-0.333910411		the total change over 8 quarters	

Table 18.*Local Projections approximate values for IRF and the confidence bounds for United Kingdom*

United Kingdom results for Local Projections			
quarter	IRF	lower confidence bound	upper confidence bound
1	1.42673303080049	-1.07798874782889	3.93145480942987
2	1.16675940025266	0.00499854350809117	2.32852025699723
3	1.37587964388522	0.0967812749204793	2.65497801284997
4	1.56210395826852	-0.159249661743075	3.28345757828012
5	0.367456538636795	-0.69034005978745	1.42525313706104
6	1.00759057251291	0.0147765568155633	2.00040458821026
7	0.250755570988586	-0.956656187191204	1.45816732916838
8	0.732627949530919	-0.694744054682789	2.15999995374463
7.889906665		the total change over 8 quarters	

Table 19.*Local Projections approximate values for IRF and the confidence bounds for United States*

United States results for Local Projections			
quarter	IRF	lower confidence bound	upper confidence bound
1	1.97653504323971	-1.4686734869364	5.42174357341581
2	0.0748331748413837	-0.859750823618158	1.00941717330093
3	0.53805705491926	-0.301387758208506	1.37750186804703
4	0.220407637608644	-0.846814645624183	1.28762992084147
5	0.199503595770099	-0.715475286782035	1.11448247832223
6	0.364308395300319	-0.451880937145324	1.18049772774596
7	0.508218628576256	-0.234614458996711	1.25105171614922
8	0.446782992839937	-0.612069107494489	1.50563509317436
4.328646523		the total change over 8 quarters	

THE IMPACT OF ARTIFICIAL INTELLIGENCE DEVELOPMENT ON LABOUR TAXATION AND PERSONAL INCOME TAX REVENUES IN THE EUROPEAN UNION

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Purpose: This paper examines the impact of artificial intelligence (AI) development on labour taxation and personal income tax (PIT) revenues in EU member states. It analyses whether the diffusion of AI technologies has influenced the structure and dynamics of labour-related tax revenues and identifies key fiscal implications associated with labour market transformation and automation processes.

Design/methodology/approach: The study applies a quantitative, comparative approach based on panel data from 21 EU countries for 2021-2023, a period characterised by accelerated post-pandemic digitalisation. Due to non-normal data distribution, Wilcoxon signed-rank tests were used to assess changes in PIT revenues and labour taxation as shares of GDP and total tax income. A random-effects panel model was estimated to examine the relationship between labour taxation and digital development (DESI). Spearman's rank correlation was used to assess the association between the AI Preparedness Index and GDP per capita. Data were obtained from Eurostat, the National Tax List, DG CONNECT, and Oxford Insights.

Findings: The results indicate a temporary deterioration of labour-based tax revenues between 2021 and 2022, followed by a statistically significant rebound in 2022-2023. These short-term fluctuations appear linked to post-pandemic recovery dynamics rather than long-term structural shifts. The panel model does not confirm that higher labour taxation supports digital development; instead, rapid improvements in DESI reflect EU-wide dynamics rather than national fiscal structures. A strong positive correlation between AI readiness and GDP per capita highlights persistent disparities, with wealthier economies more capable of adopting advanced technologies. Overall, the fiscal effects of AI diffusion remain uneven across the EU and strongly dependent on countries' economic and digital maturity.

Research limitations/implications: The analysis covers a short three-year period and relies on aggregated indicators, which may not fully capture the long-term or sector-specific fiscal effects of AI. Future research should incorporate longer time series, additional tax categories (e.g., CIT, VAT), and more detailed labour-market indicators.

Practical implications: Policymakers should anticipate potential revenue shifts resulting from automation and adjust fiscal frameworks to ensure balanced taxation between human labour and AI-enabled production.

Social implications: As AI reshapes employment structures, its development may influence income distribution and social stability. Strengthening redistribution mechanisms and reskilling programmes remains essential to mitigate potential inequalities.

Originality/value: This study provides one of the first empirical assessments of AI's fiscal implications for labour taxation and PIT revenues across EU member states, offering relevant insights for researchers and public finance policymakers.

Keywords: artificial intelligence, labour taxation, personal income tax revenues, automation and employment, European Union.

Category of the paper: Research paper.

1. Introduction

The rapid spread of artificial intelligence (AI) has enabled the automation of numerous tasks previously performed by humans. In the short term, this process may significantly affect labour markets by increasing the risk of unemployment. Unlike previous industrial revolutions, the diffusion of AI is expected to replace not only routine and low-skilled occupations but also jobs requiring higher competencies. Consequently, technological changes may disproportionately affect middle-income earners.

This group plays a crucial role from the perspective of tax systems, which in many EU countries rely heavily on revenues generated from labour income. At the same time, a growing body of research indicates that the wider adoption of AI can enhance labour productivity and increase the incomes of both enterprises and employees. Therefore, the development of AI does not necessarily lead to declining tax revenues; instead, it may even contribute to their growth through higher productivity and wage dynamics.

Despite the expanding literature on the impact of AI on employment, productivity, and economic growth, relatively few studies address its fiscal implications—particularly those related to personal income taxation. There remains a noticeable gap in empirical research examining whether, and to what extent, automation processes influence the structure and dynamics of budget revenues in European Union (EU) member states. This study aims to address this gap by providing the first comparative analysis focused specifically on labour taxation and PIT revenues in the context of increasing AI diffusion.

The purpose of this article is to identify whether the development of artificial intelligence affects the level and structure of labour-related tax revenues and to determine the direction and magnitude of this impact. The empirical analysis applies nonparametric statistical tests for dependent and independent samples, allowing for the assessment of temporal changes and cross-country differences within the EU. The article is structured into five sections. Following this introduction, Section 2 presents the literature review; Section 3 describes the research methodology and data; Section 4 provides the empirical results; and Section 5 discusses conclusions and policy implications.

2. Literature review

Artificial intelligence (AI) has become a major driver of structural transformation in modern economies by automating tasks traditionally performed by humans. The current technological revolution is unprecedented, as AI is no longer confined to routine or mechanical activities but increasingly replaces predictable, experience-based tasks once considered exclusive to human labour (Ford, 2015). Intelligent systems are evolving beyond the role of tools and are now functioning as autonomous “co-workers”, capable of independent decision-making and complex analytical operations (Wajcman, 2017).

The growing use of AI has profound implications for labour markets. The International Labour Organization identifies clerical and administrative occupations—including secretaries, accountants, data-entry clerks, customer service representatives, and banking staff—as among the most automation-prone professions (Gmyrek et al., 2023). Approximately 24% of such jobs face a high risk of automation, and another 58% are at moderate risk. Similarly, the International Monetary Fund (IMF, 2024) estimates that around 40% of global employment may be affected by AI, with the impact being particularly significant in high-income economies, where 5-6% of all jobs are highly vulnerable, compared to only 0.4% in low-income countries.

Empirical studies indicate that automation’s adverse effects are concentrated in low-skilled production and service sectors and disproportionately affect men and individuals at both ends of the age distribution (Tamayo et al., 2025). Highly developed countries—which rely heavily on personal income taxes as a stable source of budget revenue—are more exposed to fiscal losses arising from reduced labour force participation (Gupta, 2007). At the same time, these countries maintain extensive welfare systems, which amplify public-spending pressures during labour-market disruptions.

Without adequate institutional responses, the adoption of AI may exacerbate income inequality (IMF, 2024). Governments are therefore encouraged to strengthen social-protection systems and implement reskilling programmes for workers affected by automation. Nevertheless, AI also offers substantial economic benefits. Productivity increases driven by AI enhance overall economic performance and, consequently, expand the tax base through higher labour and capital incomes (Stevenson, 2018).

The fiscal impact of AI is closely tied to the situation of the middle class, which constitutes the largest and most stable group of personal income taxpayers. Middle-income earners in Denmark, Belgium, Germany, and Finland bear the highest tax burden in the European Union, making these countries particularly sensitive to potential decreases in PIT revenues resulting from automation (Dolls et al., 2023). In developing countries, personal income taxes play a central role in financing public goods and supporting welfare systems (Bird et al., 2005). A reduction in PIT revenues could therefore intensify inequality and restrict access to essential social services (Beljić et al., 2025).

Middle-income taxpayers remain especially vulnerable because they lack both the sophisticated tax-optimisation tools available to high-income groups and the exemptions targeted at low-income earners (Panskov, 2016). The stability and legitimacy of the tax system depend on maintaining this group's economic security and fiscal engagement (Kalambokidis, 2014).

AI-driven automation also generates long-term public-finance challenges. Rising unemployment leads to higher welfare expenditures, placing a sustained burden on public budgets (Çelikay, 2022). The development of automation technologies particularly affects manufacturing, retail, and transportation sectors, where repetitive tasks can be fully replaced by AI-based systems (Tschang, Almirall, 2021). Although such substitution may initially reduce employment, it can also foster productivity growth and create new opportunities through emerging occupations and redefined job roles (Saam, 2024).

In summary, the literature highlights that the diffusion of AI generates both risks and opportunities for labour markets and tax systems. Automation may reduce employment in routine and predictable occupations, challenging the stability of labour-related tax revenues, but it can simultaneously stimulate innovation, enhance productivity, and expand fiscal capacity in the long term (Teigland et al., 2025). Balancing technological progress with fiscal sustainability—particularly by supporting the middle class—remains a key challenge for governments in an era of AI-driven economic transformation. To strengthen the theoretical foundation of this study, a systematic literature review (SLR) was conducted following widely recognised guidelines for transparent and reproducible literature screening. The review covered the years 2010–2025, a period reflecting the most dynamic phase of AI diffusion and associated labour-market transformations. Three academic databases—Scopus, Web of Science, and Google Scholar—were searched using combinations of the following keywords: “artificial intelligence”, “AI”, “automation”, “labour taxation”, “tax revenues”, “employment”, “personal income tax”, “PIT”, “digitalisation”, “DESI”, “AI preparedness”. Studies focusing on national taxation systems, labour-market outcomes of automation, and macroeconomic implications of AI were included. After removing duplicates and non-relevant items, 128 publications were analysed in full. The review revealed extensive research on AI's effects on employment, productivity, and inequality, but very limited empirical evidence on fiscal outcomes—particularly in relation to PIT revenues and labour taxation structures. Although existing literature offers valuable insights into how AI-driven automation reshapes employment patterns, productivity, and income distribution, the fiscal dimension of these transformations remains significantly underexplored. Most studies focus on labour displacement, wage polarisation, and productivity gains, while only a small number assess how technological change affects tax structures. Even fewer works examine the consequences for personal income taxation, despite PIT being the primary revenue source for many European welfare states. Additionally, cross-country comparative analyses linking AI diffusion, labour taxation, and fiscal performance are virtually absent. As a result, there is limited understanding of

whether and how AI adoption influences labour-based tax revenues across EU member states, particularly in the short term. According to the systematic literature review conducted, no prior studies were identified that empirically investigate the relationship between AI development and labour taxation or PIT revenues in EU member states. This confirms the existence of a clear research gap that the present study aims to address.

3. Methods

The primary objective of this study is to examine the effects of artificial intelligence (AI) development and adoption on personal income tax (PIT) revenues across the member states of the European Union. The initial sample comprised 25 EU countries; nevertheless, four countries were excluded from the analysis due to systematically missing observations, resulting in a final balanced panel of 21 countries for the period 2021–2023. This timeframe was selected as 2021 marks the onset of a substantial acceleration in AI diffusion and digital transformation within the post-pandemic economic landscape.

The empirical strategy consists of three complementary components:

1. nonparametric tests examining changes in PIT revenues relative to GDP and total taxation,
2. a panel data model explaining cross-country differences in digital development (DESI),
3. a correlation analysis assessing the relationship between AI readiness and economic development.

Data on PIT revenues, GDP, total taxation and labour-related tax structure were obtained from the National Tax List and Eurostat. Because the variables did not satisfy the normality assumption (verified using the Shapiro-Wilk test), the Wilcoxon signed-rank test was applied to evaluate changes in the tax base between 2021–2022 and 2022–2023.

To analyse cross-country variation in digital development, a panel regression model was estimated using the Digital Economy and Society Index (DESI) as the dependent variable. DESI serves as a proxy for AI readiness, as digital infrastructure, digital skills and technological integration are necessary preconditions for effective AI adoption. DESI, while broader than strictly AI-focused indices, captures the foundational infrastructure and skills necessary for AI diffusion and thus serves as a suitable proxy for early-stage AI readiness. The IMF's AI Preparedness Index (APII) was used only in the cross-sectional correlation analysis because it is available for a single year (2023) and cannot be included in a panel model.

The following hypotheses were formulated:

- H1 (TAX_LAB): Countries with a higher share of labour taxes in total taxation exhibit a higher level of digital development (DESI).
- H2 (GDP per capita): Higher GDP per capita ($\ln\_GDP\_PC$) is positively associated with DESI.
- H3 (Unemployment): Higher unemployment rates (UNEMP) are associated with lower DESI.
- H4 (Income inequality): Higher income inequality (GINI) is associated with lower DESI due to limited access to digital skills and infrastructure.

The key explanatory variable TAX_LAB measures “taxes on labour as % of total taxation”, including PIT from labour income and social security contributions. Control variables include log GDP per capita, unemployment rate, and the GINI coefficient. Other tax categories such as VAT or CIT were excluded because they are not directly labour-dependent and therefore do not allow for isolating the fiscal effects of potential AI-driven labour market restructuring.

To estimate the effect of labour taxation on digital development, the following panel data model was specified:

$$DESI_{it} = \alpha + \beta_1 TAX\_LAB_{it} + \beta_2 GDP_{it} + \beta_3 UNEMP_{it} + \beta_4 GINI_{it} + \lambda_t + u_{it}$$

where:

$DESI_{it}$ – digital development in country i in year t ,

TAX_LAB_{it} – share of labour taxes in total taxation,

GDP_{it} – GDP per capita (logged),

$UNEMP_{it}$ – unemployment rate,

$GINI_{it}$ – income inequality,

λ_t – time effects for 2022 and 2023,

u_{it} – random disturbance.

A Hausman test comparing fixed-effects (FE) and random-effects (RE) estimators yielded a result of $\chi^2(3) = 6.50$, $p = 0.0898$. With no grounds to reject the null hypothesis, the RE estimator was selected as consistent and efficient. This indicates that unobserved country-specific effects are not systematically correlated with the regressors. To address heteroskedasticity and within-country autocorrelation, cluster-robust standard errors were used (clustered at the country level). A supplementary Spearman correlation analysis evaluated the link between AIPI (2023) and GDP per capita. Given the short length of the panel ($T = 3$), cross-sectional variance is naturally limited, which results in low between and overall R^2 values; however, this does not undermine the validity of within-country estimates, which remain the primary focus of the analysis.

4. Results

The results provide evidence on the evolution of labour-related taxation in the EU during 2021-2023 and on the determinants of digital development. The analysis begins with a nonparametric assessment of PIT revenue dynamics, followed by the panel regression model and the complementary AIPI-GDP correlation.

The Wilcoxon signed-rank test indicated a statistically significant decline in the share of PIT revenues relative to GDP between 2021 and 2022. As shown in Table 1, PIT/GDP decreased in 21 countries, while it increased in only 7, with the decline being highly significant ($p = 0.0054$).

Table 1.

Change in the Share of PIT Revenues Relative to GDP in 2021-2022

Sign	Obs	Sum Ranks	Expected
Positive	7	81	203
Negative	21	325	203
Zero	0	0	0
All	28	406	406
Parameter		Value	
Unadjusted variance		1928.5	
Adjustment for ties		-4.25	
Adjustment for zeros		0	
Adjusted variance		1924.25	
Z statistic		-2.781	
p-value (Prob > z)		0.0054	

Source: Own elaboration based on Eurostat (PIT, GDP, labour taxes), DG CONNECT (DESI), and Oxford Insights (AIPI).

For the period 2022-2023, the trend reversed. Seventeen countries showed an increase in the PIT/GDP ratio, nine a decrease, and two no change. The increase was statistically significant ($p = 0.0304$), indicating a recovery of labour-based tax revenues (Table 2).

Table 2.

Change in the Share of PIT Revenues Relative to GDP in 2022-2023

Sign	Obs	Sum Ranks	Expected
Positive	17	296.5	201.5
Negative	9	106.5	201.5
Zero	2	3	3
All	28	406	406
Parameter		Value	
Unadjusted variance		1928.5	
Adjustment for ties		-1	
Adjustment for zeros		-1.25	
Adjusted variance		1926.25	
Z statistic		2.165	
p-value (Prob > z)		0.0304	

Source: Own elaboration based on Eurostat (PIT, GDP, labour taxes), DG CONNECT (DESI), and Oxford Insights (AIPI).

To test hypotheses H1-H4, the panel model with random effects was estimated. The results are summarised in Table 3.

Table 3.

Results of the Random-Effects Panel Regression (Dependent Variable: DESI)

Variable	Coefficient	Std. Error
TAX_LAB	-1.297	(0.794)
GDP	0.00000175	(0.00000196)
UNEMP	0.646	(2.414)
GINI	-0.813	(0.936)
2.tis	7.230**	(2.940)
3.tis	11.14***	(3.017)
_cons	147.5***	(36.04)
Statistic		Value
R ² within		0.636
R ² between		0.0529
R ² overall		0.00189
N		63

Standard errors in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Own elaboration based on Eurostat (PIT, GDP, labour taxes), DG CONNECT (DESI), and Oxford Insights (AIPI).

The TAX_LAB coefficient is negative and statistically insignificant, leading to rejection of H1. Higher labour taxation does not correspond to higher digital development. GDP per capita (H2), unemployment (H3), and income inequality (H4) show expected signs but lack statistical significance. Strong and highly significant time effects reveal a rapid EU-wide rise in DESI in 2022 and 2023, independently of national economic structures.

To complement the panel results, a Spearman correlation was conducted between AIPI (2023) and GDP per capita.

Table 4.

Correlation Between AI Preparedness Index and GDP per Capita

Test	Value	N
Spearman's rho	0.6692	25
Spearman's p-value	0.0003	25
Shapiro-Wilk (AI Index)	0.93226	25
Shapiro-Wilk p (AI Index)	0.09801	25
Shapiro-Wilk (GDP)	0.9496	25
Shapiro-Wilk p (GDP)	0.24558	25

Source: Own elaboration based on Eurostat (PIT, GDP, labour taxes), DG CONNECT (DESI), and Oxford Insights (AIPI).

The correlation is strong and statistically significant ($\rho = 0.6692$, $p < 0.001$). Higher GDP per capita is strongly associated with greater AI readiness, supporting the theoretical expectation that economic development facilitates investment in innovation and digital infrastructure.

5. Discussion

The findings of this study offer new insights into the evolving relationship between labour taxation, digital development, and artificial intelligence (AI) diffusion in EU member states during the period 2021–2023. The observed changes in the structure of labour-based taxation—captured through PIT-to-GDP ratios—align with broader economic and technological dynamics affecting European labour markets in the post-pandemic period. The statistically significant decline in PIT revenues between 2021 and 2022 supports earlier evidence that temporary fiscal interventions implemented during the COVID-19 recovery, such as payroll tax reliefs and employment subsidies, reduced the effective tax burden on labour. However, the subsequent statistically significant increase in 2022–2023 indicates that these changes were not structural but rather short-term policy effects. The rebound suggests a return to pre-pandemic tax structures as inflation, labour market tightening and fiscal consolidation efforts intensified across the EU.

The panel regression results extend these observations by analysing the determinants of digital development. Contrary to the directional expectations formulated in H1, the share of labour taxation in total revenues (TAX_LAB) does not significantly explain differences in DESI scores across EU member states. This finding suggests that labour taxation alone does not appear to accelerate or hinder digital transformation during the early phase of widespread AI adoption. The absence of significant coefficients for GDP per capita, unemployment and income inequality further indicates that structural economic differences did not strongly differentiate countries' digital trajectories between 2021 and 2023. Instead, the strongly significant time effects reveal that DESI increased rapidly and uniformly across all EU countries. This pattern reflects EU-wide investments in digital public services, broadband expansion and skills development, which collectively shaped digital progress more substantially than the national structural variables included in the model.

The correlation analysis further contextualises these findings. The strong, positive and statistically significant relationship between the IMF AI Preparedness Index and GDP per capita underscores the role of economic development as a fundamental enabler of AI readiness. Wealthier countries demonstrate greater capacity to invest in digital infrastructure, innovation ecosystems and human capital—all prerequisites for effective AI deployment. This result is consistent with the broader literature emphasising that AI adoption is closely linked to financial resources, institutional maturity and technological capability (IMF, 2024; ILO, 2025). It also reinforces the interpretation that digital transformation during 2021–2023 was shaped more by general economic development and coordinated policy frameworks than by differences in labour taxation.

The discussion of labour taxation must therefore be situated within a broader debate on the long-term fiscal implications of AI. Prior research highlights mixed effects: AI may displace routine and middle-skill occupations, potentially eroding the PIT base, but it may also generate productivity gains, increase compliance through digitalisation of tax administration, and create new high-value jobs (Stevenson, 2019; Challoumis, 2025). The results of this study reflect this duality. The initial drop in PIT/GDP in 2021-2022 could signal early labour market adjustments, but the rebound in 2022-2023 suggests that AI adoption did not produce immediate negative effects on PIT revenues. Short-term disruptions were offset—at least temporarily—by rising employment, wage growth and increased taxable income in sectors that benefited from digital acceleration.

Taken together, the findings indicate that the relationship between AI diffusion and labour-based taxation is neither linear nor immediate. Instead, digital transformation interacts with fiscal systems through multiple overlapping mechanisms: changes in employment structure, productivity dynamics, sectoral shifts, the digitalisation of tax administration and national fiscal responses. The uniform rise in DESI scores across the EU highlights the importance of coordinated policy initiatives in shaping digital progress, while the strong link between GDP and AI readiness underscores persistent structural disparities. The evidence suggests that AI adoption alone cannot explain short-term fluctuations in PIT revenues; rather, these changes must be analysed within a comprehensive framework that integrates technological, economic and policy-driven factors.

6. Summary

This study analysed the early fiscal implications of artificial intelligence (AI) development for labour taxation and personal income tax (PIT) revenues in EU member states during the period 2021-2023. The empirical findings show a statistically significant decline in the importance of PIT revenues in 2021-2022, followed by a clear rebound in 2022-2023. These short-term fluctuations appear to be driven primarily by post-pandemic fiscal adjustments, transitional labour-market dynamics and temporary policy interventions rather than by structural technological change. The panel regression model further demonstrates that labour taxation (TAX_LAB) does not significantly influence levels of digital development (DESI), while strong time effects indicate a uniform rise in digitalisation across EU countries. A complementary Spearman correlation confirms a strong and positive association between AI readiness and GDP per capita, highlighting persistent structural disparities in the capacity of countries to adopt advanced technologies.

The research contributes new evidence to an underexplored dimension of AI-driven transformation by directly linking AI diffusion with labour-related tax revenues. Existing literature has focused predominantly on employment, productivity and inequality, while the fiscal effects—particularly those concerning PIT—remain insufficiently examined. By addressing this gap, the study provides one of the first cross-country assessments of how AI-related developments may influence labour-based taxation in the short term.

The interpretation of the results requires caution due to several limitations inherent in the study. The short observation period (2021–2023) captures only the initial phase of AI diffusion and does not allow for the evaluation of long-term fiscal consequences. The panel comprises only 21 countries, which constrains statistical power. Moreover, the use of aggregated indicators such as DESI, TAX_LAB and the GINI coefficient may obscure sector-specific or institutional nuances. Finally, the AI Preparedness Index is available for a single year, which restricts the analysis to cross-sectional associations rather than dynamic trends. These limitations indicate the need for future research based on longer time series, additional tax categories (such as CIT and VAT), and more granular labour-market or sector-level data.

Despite these limitations, the study offers meaningful implications for policymakers. As AI continues to reshape employment structures and production processes, governments should anticipate potential shifts in revenue sources and consider adjustments to fiscal frameworks that balance taxation between human labour and AI-enabled production. Strengthening digital readiness, improving tax administration through advanced technologies, and supporting reskilling initiatives will be essential to ensure fiscal stability and reduce inequality in the evolving technological landscape.

Overall, the findings highlight that the relationship between AI diffusion and labour-based taxation is complex, non-linear and closely intertwined with broader economic conditions and institutional capacities. Continued research will be necessary to understand the long-term fiscal impacts of AI and to support evidence-based policymaking in an era of rapid technological change.

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EU ETS – AN EMPIRICAL STUDY OF MARKET DYNAMICS AND CORPORATE STRATEGIES IN THE SECOND AND THIRD TRADING PERIODS (2008-2020)

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Purpose: The research aims to identify how enterprises adjusted their trading strategies, participation intensity, and risk management approaches in response to evolving EU regulations and changing market conditions. The study also seeks to examine the structural differences between small and large enterprises and their approaches to trading emission allowances and derivatives.

Design/methodology/approach: The research combining quantitative and qualitative analyses. The study is based on secondary data from official reports published by relevant institutions. The theoretical scope of the paper covers the intersection of environmental economics and financial market behavior, emphasizing the transformation of emission allowances into fully recognized financial instruments within the EU legal framework.

Findings: The analysis revealed that during the second trading period, market activity was relatively low due to a substantial free allocation of allowances and an oversupply in the market. Most small and medium-sized enterprises engaged minimally, often purchasing allowances only to meet compliance obligations. In contrast, large utilities and industrial entities demonstrated more active behavior, particularly in the third trading period, employing strategies such as hedging, banking, and cost minimization. Rising EUA prices after 2018 encouraged a shift toward more strategic, long-term management of allowances and increased interest in emission-reduction investments.

Research limitations/implications: The study's main limitation lies in its reliance on aggregated data, with a focus primarily on the German market and EU-level statistics. Consequently, the results may not fully reflect the diversity of behaviors in smaller or less-regulated markets.

Practical implications: The findings provide valuable insights for policymakers, regulators, and corporate decision-makers involved in emission trading and environmental management.

Originality/value: This paper provides an original, comprehensive analysis of the behavioral evolution of EU ETS participants over two key trading periods. The study contributes to the understanding of how regulatory changes influence corporate decision-making and market development. Its value lies in offering both academic insight and practical guidance for policymakers, environmental economists, and corporate sustainability managers.

Keywords: Carbon finance, Carbon market, Corporate finance, ESG.

Category of the paper: General review, Viewpoint.

1. Introduction

The European Emissions Trading Scheme (hereinafter referred to as the EU ETS) is the main tool for implementing the commitments undertaken by the EU and its members in the Kyoto Protocol to the UNFCCC (UN, 2015). The system was established on 13 October 2003 and became operational in January 2005 (EU, 2003). The EU ETS operates on a cap-and-trade basis with partially free allocation. In the initial clearing periods (2005-2012), most allowances (EUA – European Union Allowance) were allocated to installations for free ("grandfathering"). In 2013, it was around 80% but in 2020 companies already received only 30% of allowances for free.

From its introduction, it was clear that the system would operate on a "learning by doing" basis. As a result, the EU ETS has undergone many changes, some of the most important of which are:

- developing rules to limit emissions leakage,
- developing details of the transition to an auction system (including the pace of transition, differentiated by sector),
- regulating the legal nature of emission allowances,
- withdrawing surplus allowances created after the financial crisis (backloading),
- establishing a Market Stability Reserve (MSR).

All these changes had an impact on the price of allowances and the behavior of companies covered by the system. Ultimately, it is the response of companies that will determine whether the targets for greenhouse gas emission reductions and the economic efficiency of these efforts are achieved. This raises the question of the strategies used by companies, whether they have adapted to the changing regulations, and what tools they are using.

This study synthesises findings from official reports, published surveys, and academic literature to examine participant behaviour in the EU ETS across the second and third trading periods (2008-2020). Key primary sources include reports from the European Commission, national authorities (DEHSt, KfW/ZEW), and industry analyses (Thomson Reuters/Point Carbon).

2. The Legal Nature of Emission Allowances

The analysis of EU ETS participants' behaviour should begin with determining the legal nature of emission allowances. According to Article 3(a) of the EU ETS Act (EU, 2003), an emission allowance is defined as the entitlement to emit an equivalent amount of CO₂ into the atmosphere, which may be freely traded (Article 12). This includes, among other actions, the transfer, sale, or cancellation of such units.

It is worth noting that the legal classification of emission allowances has varied across EU Member States. Most commonly, allowances have been described as financial instruments, intangible assets and property rights, or as commodities. In September 2016, following a recommendation by the European Court of Auditors, the European Commission initiated an investigation into the legal nature of emission allowances (European Commission, 2017a, p. 30). Since 3 January 2018, pursuant to MiFID II Directive, greenhouse gas emission allowances have been formally classified as financial instruments that are not securities (EU, 2014a, Section C). Consequently, they are also subject to the provisions of EMIR Regulation (EU, 2012) and MAR Regulation (EU, 2014b), which regulate OTC derivatives, central counterparties, trade repositories and market abuse respectively.

3. Market Structure and Corporate Strategies

3.1. Market Structure

The fact that emission allowances constitute a financial instrument and may be freely disposed of creates extensive possibilities for managing these units. Allowances can be traded on regulated exchanges and over the counter (OTC) markets and serve as the underlying asset for derivatives (futures, forwards, swaps, options). Accessible instruments based on emission allowances or related units (CERs and ERUs) on the most important exchanges are presented in Table 1.

Table 1.

Selected exchanges and financial instruments related to the EU ETS available on them

Exchange / Instrument	EUA	CER	ERU
ICE/ECX	spot (daily futures), auctions (UK), futures, options	spot (daily futures), futures, options	none (previously futures and options)
EEX	spot, auctions (PL, GER, EU), futures (monthly, quarterly, annual), options (European)	spot, futures	none (previously futures)
CME NYMEX	options (monthly), futures (monthly)	none (previously futures and options)	none (previously futures and options)
BLUENEXT	none (previously spot, futures, CER/EUA spread)	none (previously spot, auctions, futures, CER/EUA spread, Green CER)	none (previously auctions and spot)
NASDAQ OMX	none, but OTC offer includes: spot transactions (daily futures), futures (quarterly), spread contracts, swap, strip	none (previously spot, futures, forward and options)	none

Source: own elaboration based on nasdaq.com; cmegroup.com; theice.com; eex.com; bluenext.it.

Over time, many exchanges withdrew certain EUA, CER, and ERU instruments. On the one hand, this was due to regulatory changes (including those concerning the legal classification of allowances, the possibility of transferring allowances between periods, the reduction in the number of allowances from the auction and creating a Market Stability Reserve), as well as shifts in interest in particular instruments. On the other hand, trading became concentrated on ICE and EEX.

An analysis of the exchanges' offerings confirms that companies actively use exchange services and probably employing more sophisticated strategies for managing their positions in the emissions trading market. Companies are likely to use EUA, CER, and ERU units, as well as derivatives based on these units. However, the use of individual financial instruments has changed over the years (see Figure 1).

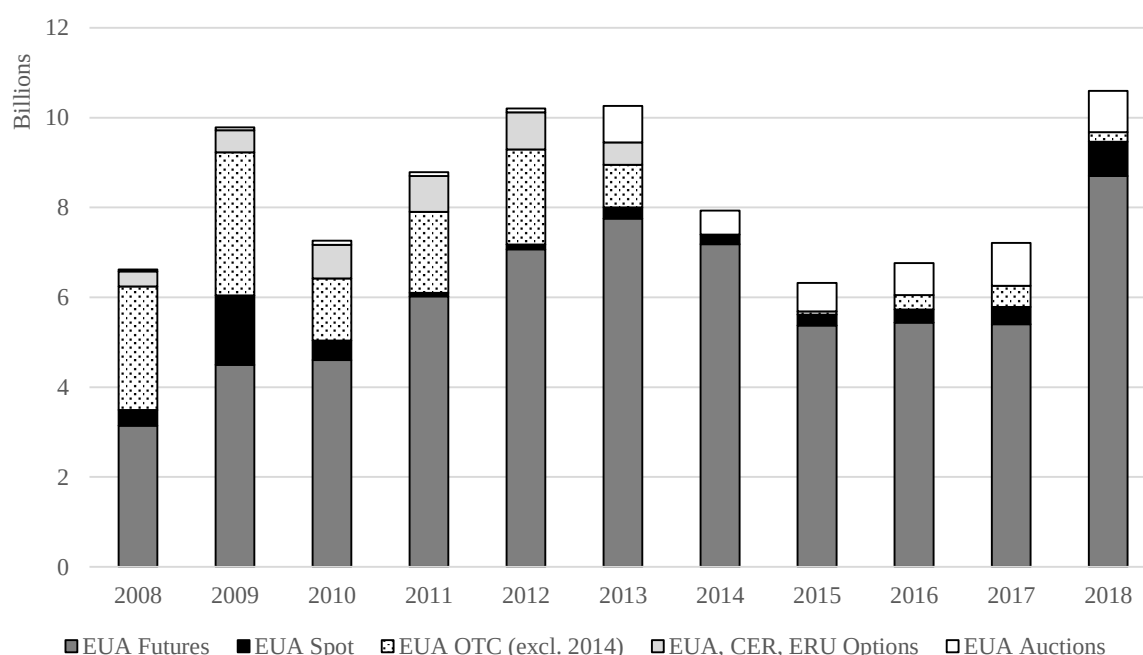


Figure 1. Volume of transactions conducted on exchange and over-the-counter markets, divided by contract type (auctions, spot, futures, options) in 2008-2018.

Source: own elaboration based on DEHST (2013, 2014a, 2015, 2016, 2017, 2018); Walner et al. (2014); European Commission (2015, 2017b, 2018, 2019).

In the early years of the second period, most emissions trading took place on the futures exchange market and the OTC market. Auctions and spot market transactions accounted for a marginal share of emissions trading (except for 2009). In subsequent years, the importance of the OTC market declined, and since the beginning of the third trading period, this market has completely lost its significance. The decline in the importance of the secondary market after 2009 was due to a loss of confidence among participants because of cases of VAT fraud (so-called VAT carousels) and theft of rights from user accounts in the register (so-called phishing) in previous years. As the free allocation of allowances (grandfathering) began to be phased out (since 2013), auctions began to gain in importance. However, the largest trading in allowances continues to take place through futures contracts. Importantly, the purchase of

a derivative instrument entails the physical delivery of the underlying asset. The relatively small share of spot market transactions in the total trading volume indicates active position management by participants in the emissions trading market.

3.2. Enterprise involvement in emissions trading during the Second and Third Trading Period

Survey data collected among German enterprises indicate that in 56% of cases emissions trading activities are managed by a single individual, while 29% of firms have a dedicated, permanent team for this purpose (KfW/ZEW, 2011, p. 34). Over the years the proportion of companies showing no inclination to engage in emissions trading has declined: in 2009, 87% either did not participate or traded only once a year, whereas by 2015 this figure had fallen to 69% (see Figure 2). At the same time, the number of companies trading daily increased. It is also worth noting that among companies that do not engage in trading at all, there are more small enterprises than large ones (KfW/ZEW, 2011, p. 24).

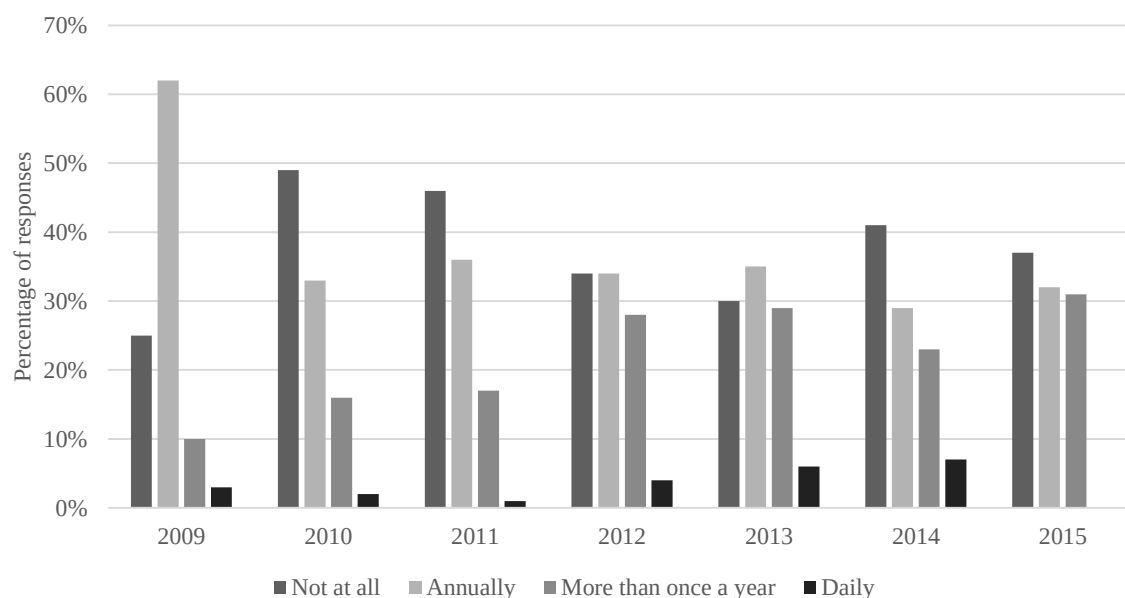


Figure 2. Frequency of Emissions Trading among Surveyed Enterprises, 2009–2015.

Source: Author's own elaboration based on KfW/ZEW (2010–2016).

Among reasons for non-participation the most frequently cited was “sufficient free allocation” (approximately 50%) (see Figure 3). Since 2013, fewer companies have cited this reason for not participating in emissions trading.

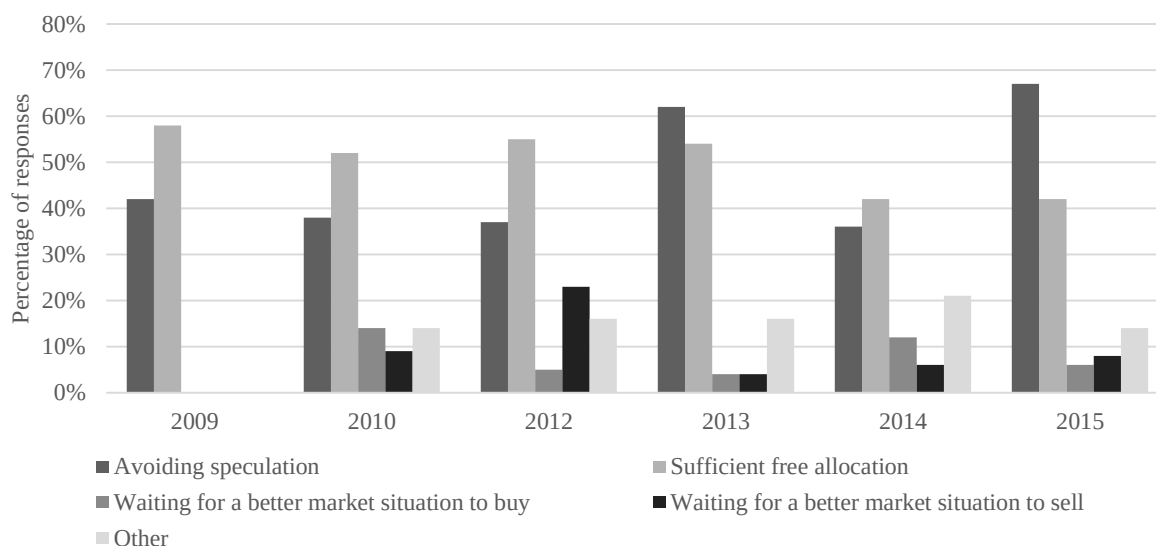


Figure 3. Reasons for Lack of Corporate Engagement in Emissions Trading (multiple answers possible). Source: Author's own elaboration based on KfW/ZEW (2010-2016).

This is understandable when one analyzes the supply and demand for allowances in the second trading period (Figure 4). Between 2009 and 2012 free allocation exceeded actual emissions, amplifying the surplus in the market (see Figure 4). This confirms the reasons for non-participation indicated by companies during this period (sufficient free allocation). The allocation principles ($\approx 90\%$ free allocation) and reduced output during the 2007-2010 crisis produced a sustained oversupply of units. The effect of this surplus was a drop in allowance prices, which explains the increase in the share of responses "Waiting for a better market situation to sell".

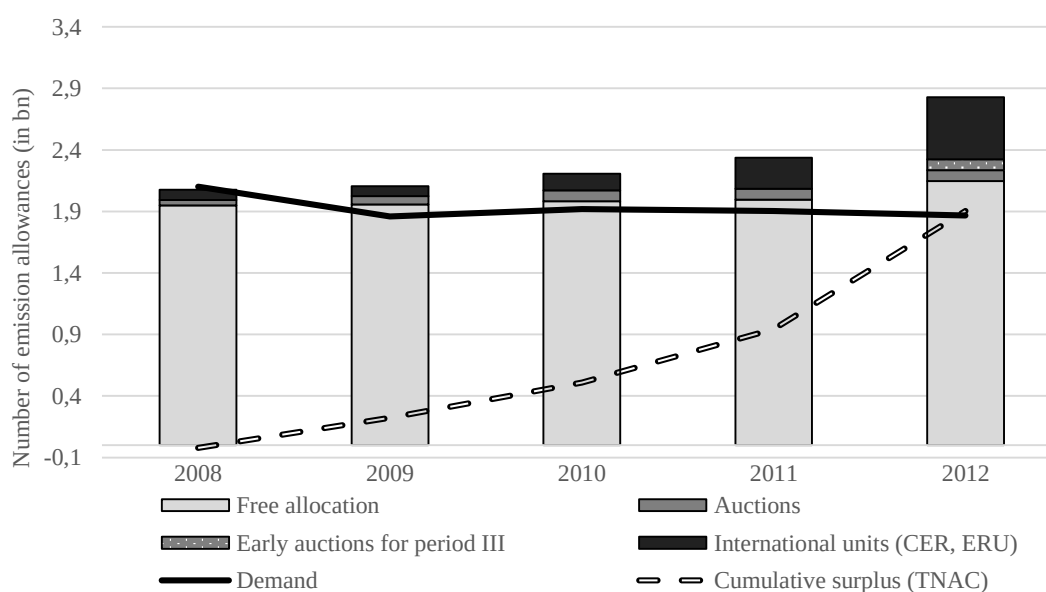


Figure 4. Structure of Supply and Demand for Emission Allowances (EUA, CER, ERU) during the Second Trading Period, 2008-2012 (approximate values).

Source: Author's own elaboration based on European Commission (2012a, 2012b, 2017a).

Furthermore, research shows 80% of firms used a single acquisition channel and 17% used two (DEHST, 2014b). The most common channel by number of firms in the second period was within-group transfers (38%), but this represented only 5% of cumulative volume—used for minor shortfalls (Tabel 2). The OTC market accounted for the largest share of traded volume. Intermediaries (brokers, dealers, banks) played a major role in facilitating transactions.

Table 2.

Significance of EUA Acquisition Channels in the Second Trading Period (by number of companies and transaction volume, in %)

Acquisition Channel	Number of Companies	Transaction Volume
Auctions	3	12
Exchange (Secondary Market)	6	14
Intermediaries	37	26
Intra-company	38	5
OTC	16	43

Source: Author's own elaboration based on DEHSt (2014b).

SMEs typically used a single channel, relying on OTC or intermediaries for large purchases (see Table 3). Large firms were active across all segments and often used multiple channels. In the second settlement period, small enterprises did not participate in auctions at all. Large enterprises, on the other hand, were active in every market segment, clearly dominating the auction market. In addition, they more often used several purchase channels.

Table 3.

Structure of EUA Acquisition Channels in the Second Trading Period by Company Size (in %)

Category	Purchase <100,000 t SMEs	Purchase <100,000 t Large	Purchase >100,000 t SMEs	Purchase >100,000 t Large
Auctions	0	4	0	13
Exchange (Secondary Market)	13	8	0	33
Intra-group	20	24	0	13
Intermediaries	67	60	100	40
OTC	13	20	100	73

Note. Multiple responses possible.

Source: DEHSt (2014b).

There is a belief that companies are more willing to purchase allowances from other entities in the same country (*home bias*). Research shows that this is probably related to transaction costs. By using existing trade links (purchasing from current contractors), companies can minimize transaction costs. Existing trade links account for as much as two-thirds of future trade links (Hinterman, Ludwig, 2019, pp. 18-19). Importantly, this phenomenon varies between companies. This variation is partly explained by the size of the companies (smaller companies are more likely to buy from local contractors) and their location – country (Hinterman, Ludwig, 2019, p. 3). Large companies generally incur lower transaction costs than small ones (Jaraite-Kažukauske, Kažukauskas, 2015, pp. 597-599; Hinterman, Ludwig, 2019, p. 17).

3.3. Corporate Strategies in Emissions Trading during the Third Trading Period

Expenditure on missing emission allowances became significant in the third trading period. In 2012 and 2013 more than half of surveyed companies used a banking strategy, but the importance of this strategy declined in subsequent years.

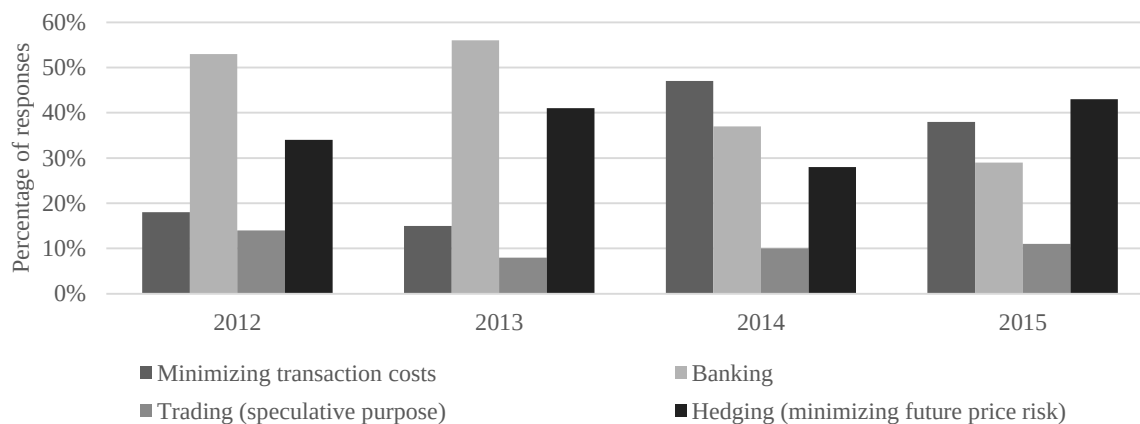
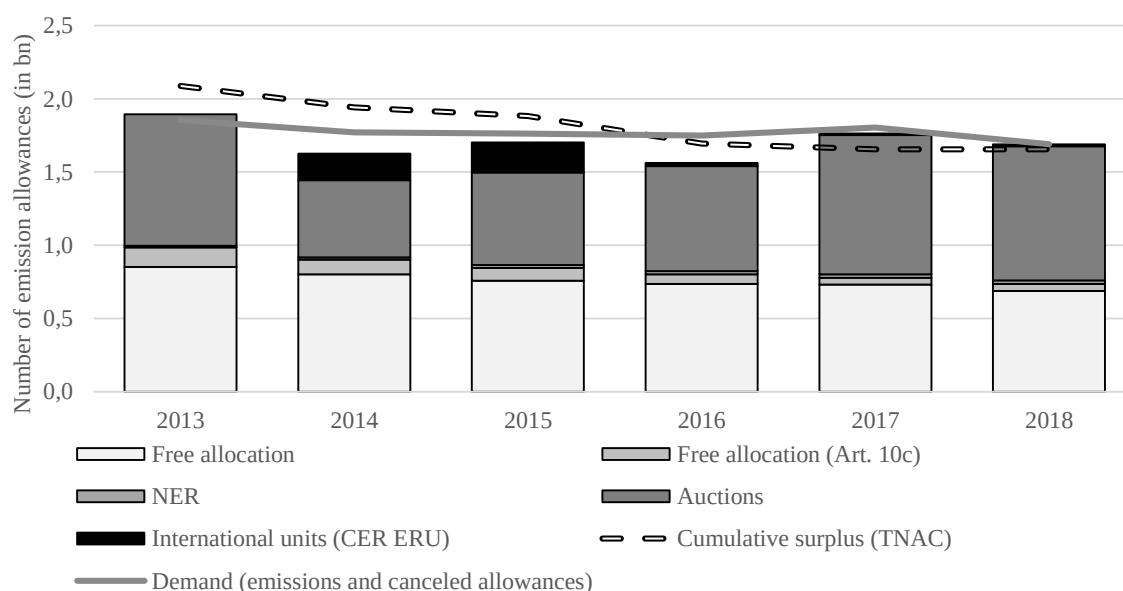


Figure 7. Strategies Used by Companies in Emissions Trading, 2012-2015.

Source: Author's own elaboration based on KfW/ZEW (2013-2016).

The importance of the banking strategy in 2012 and 2013 stemmed from the fact that companies had large surpluses of allowances. The carryover of allowances (banking) from the second to the third period contributed to a cumulative surplus of approximately 2.1 billion units in 2013 (see Figure 5).



Note. NER – new entrants' reserve. The cumulative surplus of approximately 2.1 billion units in 2013 resulted from the banking of 1,749,540,826 units from the second period and the transfer of 300 million units to the EIB for investment in demonstration projects. TNAC- total number of allowances in circulation.

Figure 5. Structure of Supply and Demand for Emission Allowances (EUA, CER, ERU) during the Third Trading Period, 2013-2018.

Source: Author's own elaboration based on European Commission (2015, 2017b, 2018, 2019) and DG CLIMA press releases.

From 2014 the strategy of minimising transaction costs gained importance: 47% of firms reported using it in 2014 compared with 15% in 2013. Many companies required only minor purchases (42%), while 21% required larger volumes – likely power and CHP plants. The frequency of cost-minimisation strategies depends on the ratio of transaction costs to allowance costs and the share of free allocation.

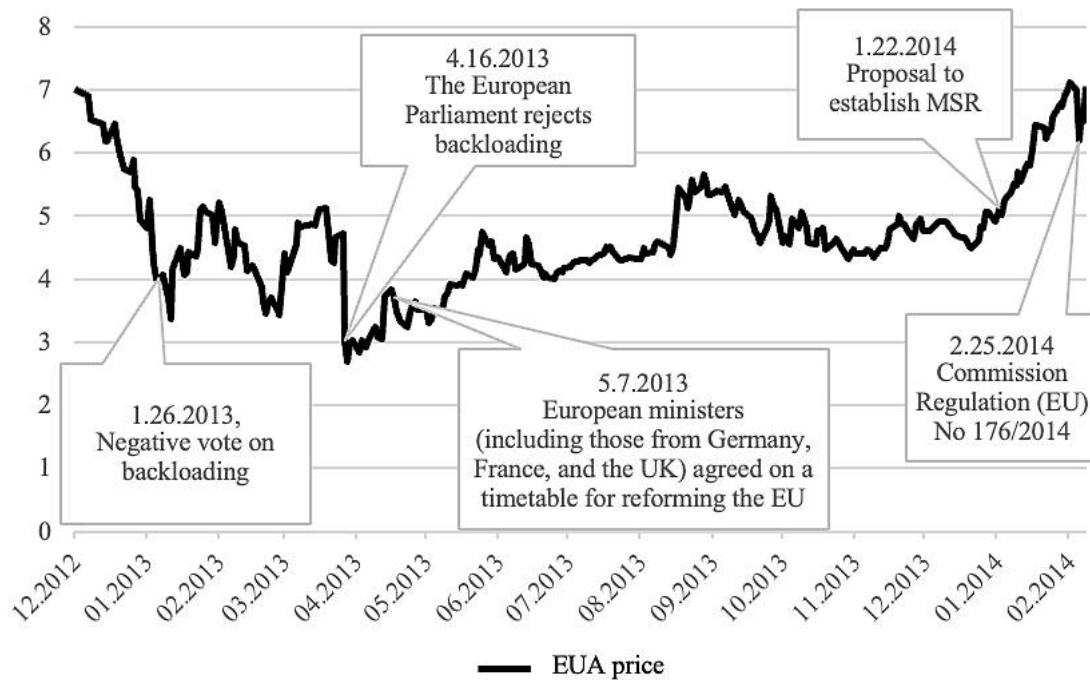


Figure 8. Impact of Backloading Developments on EUA Prices (in euros).

Source: Author's own elaboration based on European Commission press releases (ec.europa.eu/clima/news).

In the third period the percentage of companies trading for speculative purposes and engaging in hedging increased significantly. The reasons for this can be found in the uncertainty surrounding regulatory changes. Between 2014 and 2016 the EU withdrew 900 million allowances from future auctions (backloading) and later introduced the Market Stability Reserve. Following the European Parliament's final approval and Commission Regulation (EU) No 176/2014, EUA prices rose from €3 to €6.20. The impact of decisions concerning backloading and MSR on EUA prices is presented in the chart. Utilities (power and CHP plants) are primary hedgers (Melum et al., 2018; Nordeng et al., 2016).

4. Conclusion

During the second trading period, market activity was relatively low due to an oversupply in the market. Emissions management became significant from 2013 onwards. Initially, it was particularly relevant for power plants, CHP units and large industrial enterprises. As free

allocation declined and EUA prices rose, a broader set of firms became active in the market and started to use derivatives.

Using the results of the analyses described above, it is possible to characterise the behaviour of participants in the market for greenhouse gas emission allowances. At one end of the spectrum are small enterprises that adopt transaction-cost-minimisation strategies. They are generally inactive, rely on intermediaries and typically make spot purchases once a year for regulatory compliance. Trading is usually handled by a single individual. These entities show low demand and supply for EUAs, and they buy more often than they sell.

At the other end are very large entities, particularly utilities, which actively manage allowances, trade frequently across spot and derivatives markets, and often operate trading departments. They tend to hedge and occasionally act as intermediaries for subsidiaries. Large industrial firms supply a significant share of allowances due to surpluses accumulated during the crisis period.

The entities that supply a significant portion of allowances are large and very large industrial companies that saved many units during the financial crisis and economic slowdown (Melum et al., 2018, p. 14). Like very large public utility companies, they are characterized by a significant imbalance between supply and demand, although some entities have a surplus of allowances and others have a shortage. Their main strategy is acquisition, often carried out through an intermediary, unlike large companies in the public service sector.

The last group of participants consists of investors, banks, and intermediaries. Investors and banks actively participate in both futures and spot markets. They do so on the stock exchange and over-the-counter markets. In this group of entities, trading is handled by the trading department. Intermediaries also participate in all possible markets, although their mode of operation is rather passive and consists of executing client orders.

It is also reasonable to assume that since 2018, companies have been more actively seeking opportunities to reduce emissions, including relevant investments, as the price of EUAs exceeded €20 this year. According to research, at this price level, reducing EU ETS costs has become an important reason for investments resulting in emission reductions (KfW, 2014, p. 22).

The study is constrained by the availability and comparability of data. Differences in survey methodologies across sources may affect direct comparability. Future research could use transaction-level datasets to examine trading networks or extend the analysis to the fourth trading phase (2021-2030) and evaluate the effects of newer instruments and policies (e.g. CBAM). There is also potential for further study on the relationship between allowance price volatility and corporate investment in low-carbon technologies.

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MODERN TRENDS IN IMPROVING BREAD QUALITY

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Purpose: The aim of this article is to identify the characteristics of bread production innovations being implemented at the current stage of the baking industry, taking into account environmental and healthy eating aspects. The article presents research results on the use of nanowater (plasma water) in the production of wheat-rye bread. The authors also presented the results of research on wheat and rye bread produced using nanowater and tap water.

Design/methodology/approach: The literature research and the critical analysis of both, the national and foreign subject literature have been used as the research methodology.

Findings: In response to the transformations occurring within the bakery industry and considering the growing demand in Poland for bread that meets consumer quality expectations, research was conducted to examine the impact of innovations in the technological process on the improvement of bread quality. Modern trends in improving the quality of bread focus on health, natural ingredients, traditional methods and the use of modern technologies such as the use of nanowater (plasma water) in the bread production process. These technologies are becoming increasingly noticeable among bread producers. The potential benefits of using nanowater in baking stem from its unique, ordered structure, which is thought to promote biological and chemical processes occurring in dough. In this article, the authors presented the features of innovation in bread production, such as: hydrocolloids in extending the freshness of bread, the use of gases (carbon dioxide, nitrogen, air) in bread production, supplementation of bread with microelements and calcium and magnesium ions, "zero waste" technology for waste minimization, the use of plasma water (nanowater) as a base for bread production.

Practical implications: Practical implications include presenting the use of nanowater in technological processes to improve bread quality, using the baking industry as an example. Introducing nanowater into bakeries offers potential technological and quality benefits (health-promoting properties, microbiological stability). This will be an important solution for future decisions by bakery owners regarding the use of nanowater in bakeries.

Originality/value: The article may constitute a recommendation for companies/entrepreneurs in the bakery industry in the area of improving the quality of bread.

Keywords: quality of bread, the essence of innovation in the use of nanowater in the technological process of bread production, classification of innovative features of bread production such as: (hydrocolloids, supplementation of bread with microelements and calcium and magnesium ions, "zero waste" technology), hierarchy of the impact of the use of nanowater in the technological process on improving the quality of bread.

Category of the paper: research paper.

Introduction

Bread is a fundamental component of the Polish diet. When consumed in a rational manner, it plays an essential regulatory role in the human digestive system and constitutes a significant source of daily energy intake (approximately 25-30%) (Dziwkosz, 2012). Beyond its nutritional value, bread may also provide pro-health benefits, and it is precisely this type of product that attracts contemporary consumers (Gambuś, Litwinek, 2011). As many as 98% of Poles report eating bread every day, which confirms its status as a key food product in Poland and justifies its prominent position in the scientific literature.

Current trends in improving bread quality concentrate on health, natural ingredients, traditional processing methods, and the use of modern technologies (Drozd, 2021). These technologies are increasingly recognized by bread manufacturers, who continue to invest in research and development to meet growing consumer expectations (Drozd, Wolniak, 2023). Modern baking is fully aligned with the broader movement toward technological innovation (Drozd, Wolniak, 2021). The innovations presented in this article pertain directly to the technological process of bread production. Novel baking methods contribute to continuous improvement in bread quality (Drozd, 2025).

Contemporary bakery production, like any modern economic sector, requires the elimination of waste through its reduction, reuse, recycling, and composting (Oest et al., 2022). For this reason, the article discusses the “zero-waste” technology, which enables the reintegration of returned or leftover bread into the production cycle. This approach aligns with the principles of a circular economy, in which resources are continuously reused without generating unnecessary waste.

2. Characteristics of Innovativeness in Bread Production

Among the novel approaches currently recognized in Poland for improving bread quality, the following are considered particularly significant:

1. The use of hydrocolloids to extend bread freshness.
2. The application of gases (CO₂, N₂, air) in bread production.
3. Bread supplementation with trace elements and calcium and magnesium ions.
4. “Zero-waste” technology – alcohol derived from bakery waste.
5. Plasma-treated water (nanowater, clustered water) used instead of standard tap water in bread production.

Hydrocolloids represent one of the most effective groups of additives employed in the bakery industry to prolong bread freshness. These are high-molecular-weight compounds, either natural or modified, characterized by their ability to bind large quantities of water and to form colloidal systems (Ishaq et al., 2024). The most commonly used hydrocolloids in breadmaking include guar gum, xanthan gum, carboxymethylcellulose, pectins, alginates, carrageenan, and locust bean gum. Their application improves not only the structure of the dough but also significantly slows down bread staling processes, which directly contributes to longer shelf life and better consumer acceptance (Dłużewska, Krygier, 2007). The use of hydrocolloids influences the following parameters (Pirsa, Hafezi, 2023):

- water retention capacity within the crumb structure,
- delayed starch retrogradation, which is the primary cause of crumb firming during bread storage,
- crumb porosity and loaf volume, resulting in higher dough expansion and a more uniform pore distribution,
- stabilization of fat emulsions in the dough, leading to an even dispersion of fat and improved crumb softness.

It should also be emphasized that certain hydrocolloids possess prebiotic properties that support the development of beneficial intestinal microflora, thereby increasing the functional value of bakery products (Pilarska, Gawalek, 2016). A notable example is inulin, which not only improves bread texture and extends freshness but also exerts positive effects on consumer health.

Growing consumer interest in long-lasting products free from chemical preservatives has made hydrocolloids an attractive market alternative. Their natural origin and beneficial effects on bread structure and freshness contribute to their increasing use in the bakery sector (Guarda et al., 2004). The implementation of hydrocolloids aligns with the demands of the modern bakery market, where natural composition, functional performance, and high quality of the final product are of fundamental importance (Pahwa et al., 2016).

Technical gases such as carbon dioxide, nitrogen, and air play a significant role at various stages of bread production—from fermentation, through mixing and shaping, to packaging and storage of finished products. Their application aims to improve quality, shelf life, and product safety, while also enabling the introduction of modern, more efficient technologies in industrial baking (Chiotellis, Campbell, 2003). From the standpoint of innovativeness, dough aeration represents an advanced technological approach to modifying the structure of raw material without chemical additives. The process can be fully controlled, automated, and adjusted to specific formulation parameters. Gas injection takes place using specialized pressure mixers that allow simultaneous mixing, aeration, and cooling of the dough (Raad et al., 2025). This technology offers both ecological and economic advantages. It reduces the consumption of raw materials (e.g., flour, yeast, fat), decreases production losses, and extends product shelf life, all of which directly contribute to waste reduction (Grenier et al., 2021).

In accordance with market requirements and EU regulations, gases such as carbon dioxide and nitrogen are considered safe for use in the food industry, broadly approved, and not classified as food additives. Dough aeration is particularly useful in the production of toast bread, gluten-free bread, low-carbohydrate baked goods, and dietary products, where precise control of consistency, structure, and sensory characteristics is crucial (Verheyen et al., 2015). In toast bread, aeration contributes to a uniform fine crumb structure and greater elasticity, which improves toasting performance and prolongs freshness. In gluten-free products, which lack the natural gluten network responsible for retaining fermentation gases, dough aeration provides an innovative technological support for developing a porous structure. In dietary and low-carbohydrate bakery products, aeration enables an improvement in loaf volume and structural characteristics despite the reduced content of flour, gluten, or starch (Sroan et al., 2009).

Technical gases such as carbon dioxide, nitrogen, and air perform multidimensional functions in bread production—from supporting natural fermentation and improving texture, through controlling the atmosphere inside packaging, to enhancing the durability and safety of the final product. Their use constitutes not only an element of modern bakery technology but also a tool for ensuring quality, hygiene, and competitive advantage on the market (Kołożyn-Krajewska, 2019).

Enriching bread with trace elements and with calcium and magnesium ions represents one of the key directions in the development of functional foods aimed at improving the nutritional value of everyday food products. Bread, as one of the most frequently consumed items in the human diet, can serve as an effective carrier of physiologically important minerals, particularly in the context of widespread deficiencies of calcium, magnesium, zinc, iron, or selenium observed in the population (Kowalski et al., 2022). Supplementation of bread in this respect constitutes an efficient pro-health strategy that combines technological considerations with dietary prevention.

From a technological standpoint, the supplementation of bread with microelements may be implemented at the dough-mixing stage or by applying premixes added directly to the flour. One of the major challenges in this process is maintaining technological performance and sensory acceptability, as certain mineral salts may affect dough colour, its ability to rise, loaf volume, and flavour (Pojić et al., 2015). High calcium content may also lead to a firmer crumb structure. Iron, in turn, may react with polyphenols, causing dough greying or the appearance of a metallic aftertaste. Because of these factors, careful formulation development is required, including testing the stability and uniform distribution of minerals in the dough.

Producers of bread enriched with microelements and calcium and magnesium ions are additionally obliged to provide accurate labelling of mineral content and to clearly state their nutritional function (Ziobro et al., 2023).

The market demonstrates growing interest in functional bakery goods, including products enriched with calcium, magnesium, and trace elements. Supplementation of bread with these minerals constitutes an effective means of improving dietary quality and responding to societal needs associated with nutritional deficiencies. It represents a practical and scalable solution that can be successfully implemented both in large industrial bakeries and in smaller local establishments. Provided that appropriate technological and legal standards are maintained, mineral-enriched bread may become an important element of nutritional prophylaxis promoting a healthy lifestyle (Wolniak, Drozd, 2025).

In the context of reducing food waste, increasing attention is devoted to the “zero-waste” concept, which assumes maximal use of raw materials and the minimization of waste (Drozd, Wolniak, 2023). One of the innovative pathways for implementing this idea in the bakery sector is the processing of production waste and unsold bread into ethyl alcohol (Castello, 2019). Bakeries generate substantial quantities of waste—defective finished products, dough residues, and returned bread from retail networks. These materials may serve as a substrate for alcoholic fermentation (Yung et al., 2023). Owing to their high content of starch, sugars, and proteins, bread products create an excellent medium for microorganisms responsible for fermentation. From a technological standpoint, the production of alcohol from bread does not differ fundamentally from classical fermentation methods employed in the spirits industry (Nierzwicki, 2010).

The environmental dimension is equally important. Bread, as an organic waste material, decomposes rapidly and releases methane and other greenhouse gases during storage. Converting it into alcohol reduces the carbon footprint and decreases the volume of biodegradable waste destined for landfill sites. Alcohol production from bakery waste provides ecological, economic, and social benefits and is emerging as a realistic solution for the future of the bakery industry.

The application of plasma-treated water (nanowater, clustered water) in breadmaking represents an innovative approach aimed at improving bread quality and enhancing microbiological safety (Drozd, 2021). Water activated using low-temperature plasma is gaining recognition as a functional substitute for standard tap water commonly used in bakery operations. The presence of reactive oxygen and nitrogen species generated through plasma–water interactions imparts antibacterial, antioxidative, and physicochemical-modifying properties to plasma-treated water (Ulutürk, Gül, 2025).

A key advantage of using plasma-treated water in bread production is the improvement of microbiological safety in both the dough and the final product. Plasma-treated water also influences gluten structure and activity, contributing to improved rheological characteristics and superior parameters of the baked loaf (Ershidat et al., 2024). With respect to fermentation processes, plasma-treated water may function as a mild regulator of yeast activity, which in practice enables a reduction in processing time without compromising the quality of the final product. In terms of storage stability, bread produced with plasma-treated water demonstrates

greater resistance to mould growth and slower crumb staling. Extending product shelf life without chemical preservatives represents a significant advantage from both commercial and nutritional perspectives.

Plasma-treated water constitutes an innovative and multifaceted tool in contemporary baking. Its application allows for the enhancement of bread quality, improved microbiological stability, reduction of chemical additives, and extension of product shelf life. As an environmentally compatible technology that is relatively easy to implement, it may play an important role in the transformation of the bakery sector toward more natural production practices aligned with the expectations of modern consumers.

3. Results of the Study on Wheat–Rye Bread Produced with Nanowater

The authors of the article were engaged in cooperation with one of the bakeries participating in a research project focused on implementing an innovative technology for producing plasma-treated water (nanowater, de-clustered water) as the base component of bakery products. The bakery owner, collaborating with the authors, commissioned a specialized laboratory to analyze wheat–rye bread from their own bakery-already producing bread using nanowater - and from two other bakeries producing bread with standard tap water. These analyses constituted the final stage of the project in the participating bakery, during which an innovative technology for obtaining plasma-treated water as a base for bakery products had been developed.

In 2025, the study of wheat–rye bread covered the following parameters:

- determination of salt content, total sugars in dry matter, and fat content,
- determination of acidity and moisture,
- determination of baking yield and loaf volume,
- evaluation of bread suitability for consumption using sensory analysis.

Additionally, the study examined yeast survival in bread dough prepared with nanowater and with standard tap water during storage, after freezing, and after thawing.

The conducted tests demonstrated that wheat–rye bread made with nanowater was characterized by lower salt content (determined using the Mohr method), higher acidity, higher total sugar content in dry matter (according to the Luff-Schoorl method), higher fat content, lower moisture content, and greater loaf volume¹.

¹ The laboratory report contained percentage changes of the analyzed parameters in relation to the bread produced by the examined bakery using standard tap water. However, the authors of the article did not obtain permission from the report owner (and the bakery owner) to publish these data.

The parameters obtained for bread produced with nanowater—such as lower salt content, higher acidity, lower moisture, and greater loaf volume—are highly advantageous from the consumer's perspective and indicate an improvement in bread quality achieved solely by replacing tap water with nanowater. The presence of sugars and fats in bread is commonly regarded as less desirable. However, the sugar content in bread depends both on the initial sugar level in the flour and on the amount of sugar added during baking. The study included wheat–rye breads with different flour compositions, which may partially distort the final result. Moreover, the sugars present in bread can serve as an easily accessible energy source within a high-carbohydrate diet. Fat content in bread, in turn, results from the addition of oil-bearing plant ingredients or fats such as oils or butter. This does not automatically imply that bread containing fat is of lower nutritional value. Fat contributes to crumb tenderness, improved aroma, enhanced absorption of fat-soluble vitamins, longer freshness, and better moisture retention.

The scoring evaluation, which combined organoleptic assessment with points assigned for physicochemical indicators, demonstrated that bread produced with nanowater was the only sample to achieve the highest total score of 40 points. This is the maximum attainable rating. The presence of nanowater clearly enhances sensory quality.

Additional tests concerned yeast survival in dough subjected to storage, freezing, and thawing. Yeast viability was assessed at four time points: 0 h, 12 h, 24 h, and 48 h. In dough prepared using clustered water, yeast maintained higher viability over a longer period, particularly at 24 and 48 hours after thawing. In the sample prepared with tap water, a gradual decline in yeast activity was observed, suggesting a faster rate of cell death under refrigerated conditions or lower resistance to the stress associated with freezing and thawing. These findings indicate that clustered water may enhance yeast survival in dough after thawing, which represents an important technological advantage in industrial baking. It enables not only an extension of dough usability for further processing but may also translate into improved baking performance and more stable final product quality, especially in delayed or frozen production systems (Cacak-Pietrzak, Rakocka, 2022).

The innovative application of nanowater in bread production represents a technologically advanced attempt to modify how dough hydrates, ferments, and develops its structural properties. Plasma-activated water contains reactive oxygen and nitrogen species that influence gluten network formation, yeast metabolism, and microbiological stability. In the analysed study, bread produced with nanowater exhibited lower moisture, higher acidity, increased loaf volume, and superior sensory evaluation. These outcomes suggest that altering the physicochemical characteristics of process water can improve dough rheology and extend freshness without relying on chemical preservatives. The concept fits into broader technological trends that favour process-based improvements over additive-driven interventions and aligns with the search for more natural and technologically efficient methods of quality enhancement.

However, the evidence also shows that the advantages of nanowater are not uniform across all parameters. The observed rise in sugar and fat content indicates complex interactions between water structure and ingredient composition, which require further controlled experimentation. Differences in flour blends, fermentation kinetics, and production conditions may partly account for these variations, underscoring the need for systematic studies before drawing generalised conclusions. The improved yeast survival after freezing and thawing is promising for industrial deferred-baking systems, yet it also points to biological mechanisms that remain insufficiently understood. Consequently, although nanowater has notable potential as an innovative tool in bakery technology, its broad implementation should be preceded by comprehensive validation across diverse production contexts to confirm the stability, reproducibility, and technological reliability of the observed effects.

4. Conclusions

The innovative solutions presented for the bakery sector demonstrate a wide range of benefits, particularly increased efficiency, improved bread quality through the development of products with enhanced sensory and nutritional characteristics, optimal resource utilization, and environmental protection. Modern technologies rely on the latest scientific and technical achievements; however, they are not yet widely implemented in bakery practice. Research on nanowater, for example, suggests potential advantages such as improved rheological properties and greater stability, yet convincing evidence of its effectiveness in bread production remains insufficient. The empirical results and physicochemical assessments presented in this article likewise did not confirm the superiority of nanowater over tap water in every respect. As with all emerging technologies, bread production based on nanowater requires further systematic investigation.

The conclusions drawn from the study of wheat–rye bread produced with nanowater may be summarised as follows:

1. Sensory value: Bread made with nanowater was the only sample to achieve the maximum possible score, obtaining first-class quality.
2. Health-related properties: Reduced salt content improves the pro-health value of the product by lowering the risk of hypertension and kidney disease. Higher acidity has a positive effect on digestion, intestinal microbiota, and bread shelf life.
3. Nutritional aspects: Higher fat and sugar content increases caloric value but also enhances flavour and energy availability. Lower moisture contributes to extended durability and freshness.
4. Texture and loaf volume: Increased loaf volume improves crumb softness, elasticity, and visual appeal.

In relation to the remaining technological innovations, the following benefits for both consumers and producers may be identified:

1. Hydrocolloids play a key role in extending bread freshness without chemical preservatives by delaying staling, a process associated primarily with starch retrogradation and water loss. They increase dough viscosity and stabilize structure, which translates into improved texture of the finished product. Hydrocolloids also enhance crumb softness and elasticity, perceived sensorially as prolonged freshness. Some hydrocolloids exhibit prebiotic properties beneficial for intestinal microflora.
2. The use of gases in breadmaking influences dough aeration. Carbon dioxide affects flavour and aroma, whereas nitrogen, as an inert gas, is used in packaging to extend freshness and protect against oxidation and mould growth. From an innovation perspective, dough gasification represents an advanced technological strategy for modifying raw material structure without chemical additives.
3. Supplementation with microelements and calcium and magnesium ions can serve as an effective method of enriching the diet with essential nutrients and preventing population-level deficiencies. This approach, however, involves several technological challenges, including the selection of appropriate mineral salts. When correct technological and legal standards are maintained, enriched bread can become a meaningful component of dietary prevention promoting healthy lifestyles.
4. The “zero-waste” technology in bakery production aims at eliminating waste generation, optimizing resource use, and implementing circular economy principles. The example presented in this article—alcohol production from bread waste—combines ecological, economic, and social benefits and represents a realistic and promising solution for the future of the bakery industry.

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THE IMPLEMENTATION OF ARTIFICIAL INTELLIGENCE IN QUALITY MANAGEMENT

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Purpose: The purpose of this publication is to analyse the potential of Ai implementation in quality management.

Design/methodology/approach: Critical literature analysis. Analysis of international literature from main databases connecting with researched topic.

Findings: The analysis demonstrates that the integration of Artificial Intelligence (AI) into Quality Management (QM) represents a paradigmatic shift from reactive, compliance-oriented systems toward adaptive, predictive, and data-driven frameworks. The study identifies that AI technologies—particularly machine learning, deep learning, natural language processing, and digital twins—enable real-time quality prediction, anomaly detection, and process optimization, thereby enhancing efficiency, accuracy, and customer satisfaction. It also finds that the successful implementation of AI in QM necessitates robust data governance, ethical frameworks compliant with ISO/IEC 42001 and the EU AI Act, and new managerial competencies such as data literacy and algorithmic interpretability. Moreover, the research emphasizes that the adoption of AI transforms organizational culture by fostering interdisciplinary collaboration and continuous learning. While AI offers considerable strategic and economic benefits, it introduces challenges related to data integrity, cybersecurity, algorithmic opacity, and the sustainability of computational resources. The findings conclude that the future of AI in quality management—termed *Quality 5.0*—will rely on hybrid human-machine intelligence systems that integrate ethical governance with technological innovation to achieve sustainable and context-aware quality ecosystems.

Originality/Value: Detailed analysis of all subjects related to the problems connected with the usage analysed scientific problem.

Keywords: Artificial Intelligence; Quality Management; Quality 4.0; Quality 5.0; Machine learning; Deep learning; Digital Twins; Predictive analytics; Total Quality Management (TQM); Industry 4.0; Industry 5.0.

Category of the paper: literature review.

1. Introduction

The emergence of Artificial Intelligence (AI) as a paradigm-altering technological paradigm has reshaped the operational and strategic landscapes of modern organizations. Its application in Quality Management (QM) is arguably one of the most robust developments in the general Industry 4.0 and the new emerging Industry 5.0 frameworks. Quality management, which previously handled process control, improvement, and satisfaction, has shifted from reaction-based and manual controls to data-driven, predictive, and adaptive models. Use of AI technologies—from machine learning (ML), deep learning (DL), and natural language processing (NLP) to expert systems and cognitive automation—is one of the biggest accomplishments in the march towards Quality 4.0, a buzzword that suggests digitalization, analytics, and intelligent decision-making in quality improvement and assurance (Jacobs, Merwe, 2026; Qin et al., 2025).

Quality in the classical TQM model was something that operated through standard procedures, culture, and human potential. The AI-based model, by contrast, puts quality into an adaptive, self-improving system in real-time whose parameters it ongoingly optimizes using information in real-time. AI in QM is not a matter of technological replacement but an epistemic and operational redesign: from human decision-making to hybrid human–machine intelligence systems. The paper elaborates on the various dimensions of AI application in quality management, including conceptual foundations, technological infrastructure, managerial implication, and ethical and organizational problems associated with such change.

The purpose of this publication is to analyse the potential of Ai implementation in quality management.

2. Conceptual Foundations: From TQM to Quality 4.0

The development from traditional quality management to AI-enabled quality systems is mapped through three paradigms converging: TQM, Quality 3.0, and Quality 4.0. TQM philosophy depended on process standardization, statistical control, and people involvement. Automation, computerized data acquisition, and use of statistical software ushered in Quality 3.0. Quality 4.0, which was formulated by the American Society for Quality (ASQ) and subsequent researchers, utilizes digital technologies such as the Internet of Things (IoT), cyber-physical systems, cloud computing, and artificial intelligence (AI) for developing self-optimizing systems that are capable of predictive quality assurance (Garcia-Garcia, 2025; Xiong, 2025).

AI makes the largest contribution to Quality 4.0 through the ability to model complexity and uncertainty. Machine learning software, for instance, is able to identify slight deviations in the conditions of manufacturing before they cause defects. Neural networks are capable of foreseeing product failure, and reinforcement learning is able to optimize control systems in real time. These abilities enhance the conventional Six Sigma or Statistical Process Control (SPC) methodology in the sense that they allow systems to learn from new data in real time instead of being founded on static statistical models (Chauhan et al., 2025; Sadyraliev et al., 2025).

Further, AI supplants the epistemology of quality itself. Conventional quality metrics had depended on determinate control parameters and discrete thresholds. AI enables learning from continuous streams of non-linear interdependencies among process variables, customer input, and environmental factors, and redefine quality metrics as adaptive, dynamic attributes. This epistemological change demands a change in managerial cognition—from considering quality as conformance to specifications to considering it an emergent, dynamic attribute of smart systems.

AI implementation for quality control requires a four-layered technology stack consisting of four interconnected fields viz. data acquisition, data warehouse, analytics, and decision execution.

Data ingestion is where vision machines, sensors, and IoT systems converge to take in real-time feeds of operational information. Factory vibration, temperature, and sound sensors, for instance, supply data to predictive maintenance and quality control algorithms as inputs. Most valuable is not so much the quantity of data but its quality, traceability, and synchronization across the different steps in production.

Data integration and storage are premised on edge computing or cloud infrastructure. Cloud infrastructure delivers data aggregation at scale and model training that is centralized, whereas edge computing delivers local inference and response that is rapid. Robust data governance systems are required to ensure data integrity, cybersecurity, and compliance with standards such as ISO 9001:2015 and ISO/IEC 42001 (AI management systems).

Analytics constitutes the brains of AI-driven quality management. Machine learning algorithms find application in anomaly detection, defect classification, predictive modeling, and root cause analysis. For instance, convolutional neural networks (CNNs) will automatically scan product surfaces, whereas support vector machines (SVMs) will classify production conditions underlying deviations. Natural language processing facilitates the analysis of unstructured text data such as customer complaints or operator reports with a view to identifying latent quality defects.

Decision execution is filling control systems and management processes with AI outputs. It could be in the form of closed-loop feedback—direct manipulation of process parameters by the AI system—or decision-support displays providing actionable suggestions to human operators. In more advanced applications, digital twins—virtual replicas of manufacturing

systems—are the simulation space where AI algorithms dictate virtual interventions before being applied live on actual operations. The combination of AI and digital twins is one of the strongest enablers of predictive and prescriptive quality management (Barathkumar, Devi, 2025; Kumar, 2025; Gueorguiev, 2025; Preascilla Ioana et al., 2025; Sharma et al., 2025).

Table 1 describes aspects of AI implementation within quality management frameworks, merging technological and humanistic perspectives. It demonstrates how AI transforms the epistemological, operational, and ethical foundations of quality systems.

Table 1.

Implementation of artificial intelligence in quality management

Area of implementation	Analytical description
Conceptual Transformation	The integration of Artificial Intelligence redefines quality management from a reactive, compliance-oriented activity into a predictive, adaptive, and data-driven system. Quality becomes an evolving property of intelligent processes capable of self-learning and continuous optimization.
Technological infrastructure	AI-based quality systems are grounded in interconnected technologies such as machine learning, the Internet of Things, cloud computing, and digital twins. These elements enable real-time data collection, analytics, and feedback loops supporting autonomous quality control.
Process control and optimization	Machine learning algorithms detect anomalies, forecast process deviations, and suggest optimal parameter adjustments. Reinforcement learning enables dynamic process adaptation, minimizing variability and stabilizing product or service outcomes.
Product and service quality assurance	Computer vision and deep learning automate inspection, classification, and compliance verification. Expert systems evaluate conformity to standards and refine quality thresholds based on accumulated data.
Decision support and root cause analysis	Artificial intelligence enhances diagnostic and analytical reasoning through causal modeling, knowledge graphs, and Bayesian inference. It allows for the identification of complex interdependencies responsible for variations in process performance.
Organizational and managerial change	The introduction of AI necessitates new managerial competencies, including data interpretation, algorithmic awareness, and interdisciplinary collaboration. The role of quality managers shifts toward the supervision and governance of intelligent systems.
Ethical and governance frameworks	Effective implementation requires adherence to international AI management and ethical standards, including ISO/IEC 42001 and the EU AI Act. Transparency, accountability, and fairness become integral to quality governance.
Strategic and economic impact	The deployment of AI improves efficiency, reduces costs, and enhances customer satisfaction through predictive and prescriptive analytics. Quality becomes a strategic instrument of competitiveness and innovation.
Barriers and risks	Implementation challenges arise from data inconsistency, algorithmic opacity, cybersecurity threats, and organizational resistance. The maturity of data governance and employee readiness determines long-term success.
Future prospects (Quality 5.0)	The future of AI in quality management emphasizes human-machine collaboration, contextual awareness, and sustainability. Intelligent systems will complement human judgment, creating ethically aligned, adaptive quality ecosystems.

3. Managerial Implications and Organizational Transformation

Application of AI to quality management cannot be reduced to a technological advancement; it entails profound organizational redesign and managerial adaptation. AI systems transform the conventional decision-making structures by decentralizing decisions and substituting them with algorithmic entities invested with autonomous reasoning capacities. Managers are therefore forced to cede control of operations for meta-management—managing the design, training, and verification of intelligent systems (Borsetto et al., 2025; Yu et al., 2025).

AI adoption requires quality departments to have newer skill sets. Algorithmic thinking, data literacy, and ability to read machine learning outcomes become managerial necessities. Cross-functional collaboration between quality engineers, data scientists, and IT professionals is the order of the day. Organizational cultures must also change from compliance-oriented to experimentation-oriented. AI applications thrive on iterative learning, which requires embracing uncertainty and error as part of innovations.

Strategically, AI enables real-time alignment between organizational and quality goals. Predictive analytics enable organizations to foresee deviations before they affect performance measures such as Overall Equipment Effectiveness (OEE) or customer satisfaction levels. The predictive capability provides pre-allocation of resources and enabling greater resilience to disruption. In service industries, AI-powered quality management enables personalization, adaptive process configuration, and continuous improvement through user feedback loops.

The shift also involves reimagining the role of human expertise. AI technologies do not replace human decision-makers but supplement them with more compact analytical insights. Managers' task is to develop hybrid intelligence systems that blend algorithmic power and human contextual sense-making. Ethical governance, interpretability, and accountability checks must be instituted to avoid algorithmic recommendations that are incomprehensible and indefensible to the organizational quality policy (Al Jabri, Elgeddawy, 2025; Olteanu, Gheorge, 2025; Abduvaxidov et al., 2025).

4. Toward a Framework for AI-Based Quality Management

Despite the promise, AI uptake in quality management is beset by technical, organizational, and ethical problems. Technically, AI algorithms require huge volumes of high-quality data, yet heterogeneity, noise, and missing values typically undermine performance. In industry, legacy systems are not AI-friendly, so integration with AI architectures is costly retrofitting or data migration.

Organizationally, there is resistance to change. Quality professionals who are used to determinist approaches are wary of probabilistic or black-box models. Moreover, the lack of prescriptive regulation and standardization regimes renders certification of AI-based quality systems complicated. Although ISO 42001 (Artificial Intelligence Management System) offers a good starting point, large-scale adoption does not occur.

Ethical and legal challenges also confront AI adoption. Algorithmic bias, data privacy, and accountability for algorithmic decisions question the foundations themselves. For example, if a prediction model incorrectly classifies a product as compliant and a defect reaches market, somebody must be accountable for having made such an error—human or algorithmic. AI governance is therefore integrated into modern quality management systems. Auditable model documentation, explainable artificial intelligence (XAI) methods, and continuous auditability must be provided to ensure the ethical and legal behavior of intelligent quality systems (Salogub et al., 2025; Kaur et al., 2025; Naga Suneetha et al., 2025).

Besides this, the green aspect cannot be ignored. AI training and inference processing capacity generates energy consumption that can work in opposition to sustainability objectives. Quality management systems are therefore needed to adopt notions of green AI—model efficiency optimization, avoiding data redundancy, and congruent alignment with ESG (Environmental, Social, Governance) performance indicators.

In order to institutionalize the benefits of AI and minimize its constraints, organizations must take a converged strategy to AI-enabled quality management. This can stand on five pillars:

- **Strategic Alignment** – All AI undertakings must be directly extracted from organizational quality goals and customer requirements so that smart systems augment—not replace—the established quality mission.
- **Data Governance** – Standardized data cleansing, labeling, and acquisition processes are a must. Conformity to ISO 8000 (data quality) and ISO/IEC 27001 (information security) standards is a good starting point.
- **Model Lifecycle Management** – Ongoing monitoring, retraining, and testing of AI models discourage performance drift. Interoperability with ModelOps or QualityOps platforms allows for lifecycle visibility.
- **Human–AI Collaboration** – Applying interpretability procedures and feedback loops keeps human experience at the center. Training sessions must develop cognitive harmonization between humans and machines.
- **Ethics and Compliance with Regulations** – Following AI governance law, like the EU AI Act, keeps systems within legal and ethical bounds to ensure ongoing trust and accountability.

This model does not envision AI as an additive layer over existing quality systems but rather as an inward pressure that reshapes the entire quality landscape. The company is now a culture of learning, with data, feedback, and knowledge constantly circulating back and forth between smart algorithms and human actors.

Next-generation AI in quality management will transition into what may be labeled as Quality 5.0—a human-centered school of thought alongside Industry 5.0 philosophies. Automation and predictive analytics are the mainstays of Quality 4.0, but symbiosis between human and machine intelligence is what Quality 5.0 focuses on. Cognitive flexible, context-aware, and ethically autonomous next-generation quality systems will be the outcome.

New technologies such as generative AI, neurosymbolic machines, and quantum machine learning will further strengthen the analytical potential of quality management. Generative AI will be able to automatically generate optimal production parameters for optimum design, whereas quantum algorithms will be able to calculate multidimensional quality information at unprecedented velocities. Incorporation of AI within sustainability models (e.g., Agile-LCA, Q&I-LCA) will also enable multiple criteria optimization of quality, cost, and environmental impact simultaneously.

Nevertheless, human judgment will remain invincible. Although the European Commission emphasizes in the AI Act, final responsibility for safety and quality must lie with responsible human control. Therefore, ultimately, the path forward for AI to proceed in quality management will not just depend on technical capability but on ethical expertise—the ability to apply AI responsibly to advance human prosperity and organisational integrity.

5. Conclusion

Application of Artificial Intelligence in quality management is a transition from mechanistic to cognitive control and improvement systems. AI renders quality a predictive, adaptive, and learning process rather than a reactive discipline. Through the application of machine learning, digital twins, and autonomous analytics, organizations are able to introduce additional reliability, accuracy, and customer satisfaction. Effective deployment, however, is not merely the adoption of the technology but involves complete organizational transformation, ethical regulation, and continuous human intervention.

The next ten years will be the transition years when AI will either be a means to operational efficiency or an inherent part of organisational capability. The task ahead of researchers and practitioners is to develop frameworks that can maintain the humanist essence of quality while also taking advantage of the computational powers of artificial intelligence. That is the true promise of Quality 4.0—and the challenge for Quality 5.0.

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THE USE OF INFORMATION AND COMMUNICATION TECHNOLOGIES AND THE EFFECTS OF INNOVATIVE ACTIVITIES

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Purpose: Contemporary enterprises operate in conditions of high volatility and complexity of the environment. One of the most dynamic dimensions of this environment are infrastructural and technological factors, in which the development of ICTs can be located. ICTs are currently an essential set of tools for implementing processes, also in the area of innovative activities. Therefore, the article focuses on the importance of utilizing ICTs in enterprises and the effects of innovative activities that may be supported by the implementation of ICTs.

Design/methodology/approach: The study employs an inductive approach. The diagnostic survey method (CAWI technique) was used. A statistical analysis of quantitative data was also used. Principal component factor analysis (PCA) was performed to develop composite indexes (*CU-effects* and *CI-enterprise*), and the values of Spearman's rho correlation coefficients were determined. The empirical study was conducted on a sample of 260 large innovative enterprises in Poland in December 2024. The survey covered the area of 16 voivodeships in Poland.

Findings: The study revealed that the average level of complexity in the potential impact of ICTs on innovative activities, as well as the average level of complexity in the importance of ICTs' use in an enterprise, is at a moderately high level. Moreover, the higher the complexity of the importance of ICTs in an enterprise, the higher the values of the potential impact of these technologies on the effects of innovative activities and the complexity of the potential impact of ICTs on the effects of innovative activities.

Research limitations/implications: The article does not aim to generalize its findings to the population of innovative enterprises operating in Poland. The set of these units is highly diverse, and the research sample did not account for the proportions between the individual attributes of the companies in the population. Moreover, the analyses were based on the opinions of respondents, which errors and subjectivity could influence. The study primarily aimed to assess the general situation regarding the importance of ICTs in innovative companies, considering their potential impact on the effects of innovative activities. The directions for further research primarily involve identifying cause-and-effect relationships between the use of various technologies, systems, and ICT tools, and the effects of innovative activities.

Practical implications: Companies should pay closer attention to the benefits that may result from implementing ICTs in innovative processes. Greater attention should also be paid to the overall importance of ICTs in the activities of enterprises. Companies should estimate the potential impact of ICTs on innovation processes and develop their own procedures in this area, which may lead to increased efficiency and effectiveness in implementing various ICTs.

Originality/value: The research results presented in this study refer to Polish conditions and expand existing knowledge on the dependence between the use of ICTs and the context of achieving specific effects of innovative activities. The survey covers the most innovative sectors in Poland, and the respondents are owners or managers. Thus, the results can serve as a valuable source of guidance for executives on whether to implement ICTs and what the potential benefits may be (not only financial, but also market, process, and others).

Keywords: information and communication technologies, innovative activities, innovative enterprise.

Category of the paper: research paper.

1. Introduction

Modern enterprises, including those engaged in innovative activities, are undergoing (to varying degrees) digital transformation, in which ICTs have taken the form of the primary tool for dynamizing intra-organizational transformations (process management), as well as the relations of enterprises with external entities, e.g., as part of the implementation of projects (Łobejko, 2020; Woźniak et al., 2024). ICTs can be understood as a family of “technologies that process, collect and transmit information in electronic form” (GUS, 2009). In other words, ICTs are a set of solutions that includes both hardware, software, telecommunications networks, web applications, and modern data and information management models (Ziemba, 2018). These include 5G technology, cloud computing, big data, the Internet of Things, industrial internet, optical fibre, data centres, advanced applications, end devices, as well as online communication tools and collaboration platforms (Jagiello, 2024; Gil, 2025; Knosala et al., 2024). Therefore, it can be assumed that today they are a kind of “core” of business models, competitiveness, and market position, as well as cooperation and opening new fields for innovation, becoming one of the key success factors (Modern360, 2024; Gil, 2025). ICTs “power” enterprises (and their subsystems, e.g., innovative, financial, HR, marketing, etc.) with useful information resources and tools for their processing, as well as constitute a “bridge” between the enterprise and the broadly understood market. In principle, ICTs can be considered a kind of “meta-resource” of innovative enterprises that permeates and integrates other resource classes. The skilful use of these technologies (regardless of the specific tools, systems, etc. being discussed in a given company) may be a prerequisite not only for the operational activities of innovative entities, but also for their strategic resilience and business continuity (Zaskórski, Woźniak, 2024).

Therefore, this article highlights the importance of utilizing ICTs in enterprises, as well as the potential impact that these technologies can have on the effects of innovative activities. This issue seems, “at first glance”, simple. It can be assumed with a high degree of probability that ICTs are implemented on a large scale in enterprises (including innovative ones) and play a significant role in the implementation of various processes that support innovative activities,

yielding beneficial effects. Nevertheless, this is not always the case, and the approach to perceiving the role of ICTs in enterprises may be ambiguous. Even the implementation of ICTs is not always planned and “provided” with the operational awareness of the managerial staff.

This article presents literature considerations and the results of empirical research, looking for answers to the following questions: *What is the level of the complexity of the potential impact of the use of ICTs on the effects of innovative activities, and the importance of the use of these technologies in the enterprise?*, as well as *How is the relationship between the importance of the use of ICTs and the potential impact of the use of these technologies on the effects of innovative activities?* The primary objective of this article is to explore the relationship between the use of ICTs and their potential impact on the effects of innovative activities. The study consists of five main parts: (1) Introduction; (2) Theoretical background of the study – specification of the importance of ICTs in the activities of enterprises and their impact on processes in the enterprise; (3) Methodological assumptions of the study; (4) Description of the results; and (5) Discussion and Conclusions.

2. The importance of ICTs in an enterprise and ICTs’ impact on the effects of innovative activities

ICTs are widely used in supporting the activities of enterprises (including innovative ones), both in the perspective of short- and long-term activities (Łobejko, 2020). It can be assumed that ICTs are essential primarily in terms of (Figure 1):

- support for innovative processes, as well as dynamization and structuring of the development of innovations (products, services) – we can refer here to the issues of:
 - improving knowledge management mechanisms – digitized archiving, analysis, and sharing of data and information stimulate the learning process, allowing for better use of information resources from previous projects and faster implementation of innovations (García-Álvarez, 2015);
 - shortening the time of development and commercialization of new products/services – examples include digital twin or computer simulations, which are the basis for agile prototyping and testing of solutions (Zhu et al., 2021);
 - personalization of innovative processes – ICTs (e.g., artificial intelligence) enable the individualization of innovation on a mass scale (Marszycki, 2023);
 - reducing barriers to innovation through the use of ICT tools in marketing, communication, and cooperation with stakeholders;

- shaping and updating the company's strategy – it is necessary to refer here primarily to the possibility of integrating information resources about the company and its environment from various sources, as well as significantly improving the processes of processing and updating information resources while maintaining consistency with the pace of development of the company and the entities with which it interacts on the market (mainly customers and competitors); In this case, tools that enable the anticipation of changes in the broadly understood environment, and allows the increase in the flexibility of the company and update the development strategy, are essential (Wang, Qi, 2020; Shirazi, Hajli, 2021; Alam et al., 2022);
- improving communication and cooperation processes – at this point, it is necessary to refer primarily to enabling enterprises to enter permanent or temporary virtual and network structures (e.g. the open innovation model can be indicated here) (Sopińska, Dziurski, 2018; Nalepka, 2020); In addition, internal information and communication integration in the company is also noteworthy, related, for example, to the unblocking of communication channels between employees or between the operational and strategic levels (Jagiello, 2024);
- support for general managerial processes – here the attention can be paid to, for example, the processes of decision-making, planning and forecasting, organizing activities, monitoring processes and the state of resources, motivating, controlling and evaluating, or reporting; In principle, every management function can be supported by ICT solutions to a large extent today (Łukasik, Zaskórski, 2025); If a company decides to engage ICTs to improve general management processes, it should be aware of entering an advanced “path” of digital transformation;
- knowledge resource management and transformation of the enterprise into a model of a “learning” or even “intelligent” unit – ICTs are the basis not only for gathering the so-called organizational knowledge, but also for its verification, e.g., in terms of completeness, consistency, reliability, etc.; Moreover, ICTs (e.g. artificial intelligence) can support humans (business owners, top managers, lower management) in partial knowledge creation – but such an activity is relatively risky (Jarmooka et al., 2020); In addition, ICTs are now becoming a “tool” for agile adaptation of enterprises to the environment (e.g. by restructuring internal relations and communication channels, as well as creating new, up-to-date knowledge, based on the analysis of experience and possible errors);
- effective data collection and analysis – this can accelerate decision-making processes and increase the level of decision accuracy; Data collection and analysis can take place either automatically or with the active participation of a human; It is also worth referring here to the issue of using ICTs in identifying information needs (Łukasik, Zaskórski, 2025).

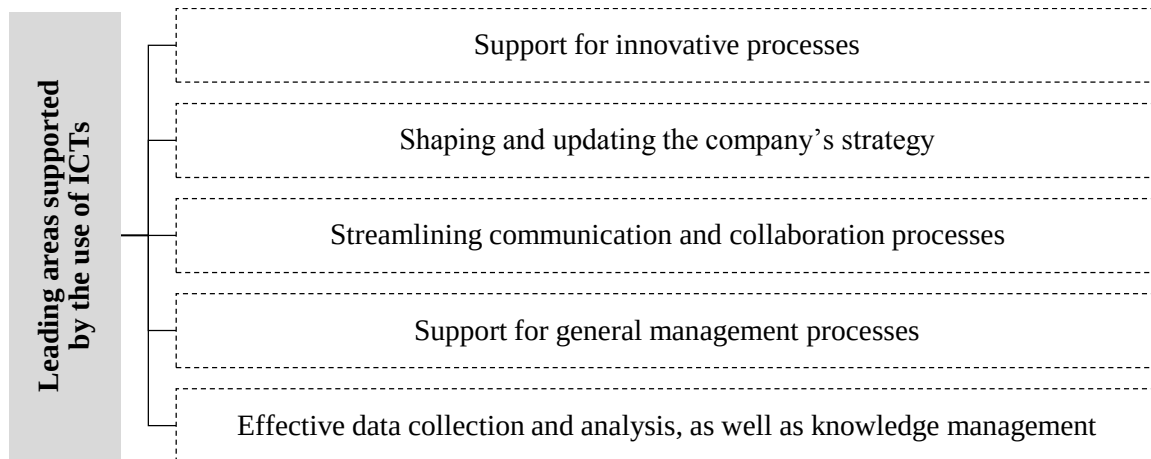


Figure 1. Leading areas supported utilizing ICTs.

Source: own elaboration.

Considering the content above, it can be assumed that the potential impact of the use of ICTs on the effects of innovative activities refers primarily to:

- information and infrastructure integration of the enterprise and its better information “embedding” in the environment, as well as better recognition of the complexity, structure, and dynamics of the enterprise’s environment (the context in which it operates and implements innovative processes) (Roger et al., 2022);
- increase operational efficiency, e.g., by automating and digitizing simple, repetitive activities (Cuevas-Vargas et al., 2016; Zhu et al., 2021; Pypłacz, Sasak, 2022);
- faster decision-making and more efficient planning, including through real-time data analytics (Zaskórski, Woźniak, 2024);
- updating and hyperscaling business models (the ability to enter new markets faster and globalize operations); It is worth referring here, for example, to the use of e-commerce platforms, digital marketing, and the sale of online services (Pakulska, Poniatowska-Jaksch, 2021);
- better management of resources (mainly human, material, and financial) – this should be indicated by reducing the number of mistakes made, greater involvement of employees in the performance of tasks, or generating greater profits, higher financial efficiency of processes, ensuring financial liquidity and expansion/modernization of ICT infrastructure, etc. (Perechuda, 2015; Gërguri-Rashiti et al., 2017; Idota et al., 2021);
- reducing the phenomenon of “digital exclusion” of the company and its employees (Sobocka-Szczapa, 2017; gov.pl, 2022);
- developing a network of relationships – we can mention here the use of digital platforms and the assumptions of the sharing economy model (Poniatowska-Jaksch, Sobiecki, 2016);
- reducing the level of risk, e.g., operational or personnel risk (Yunis et al., 2017; Wang et al., 2024);

- improving the quality of customer service and creating new shopping experiences (e.g., personalization of service and offer, as well as the use of omnichannel strategies) (Maciejewski, 2025).

Because of the considerations above, it can be noted that ICTs can have a multi-faceted impact on the implementation of innovative processes and the appearance of numerous effects (mainly beneficial for the company). In this case, we can also distinguish specific dimensions of the impact of ICTs on the effects of innovative activities (Figure 2), which interact and complement each other:

- integrative and relational – attention should be paid here to the integration of the results of the company's activities (i.e. innovations) with the existing offer of this entity, as well as to the integration of the company with the market (users, business partners, etc.) and its needs, requirements, and limitations in relation to innovation;
- HR and competency-based – this dimension mainly refers to stimulating the development of digital competences of employees (the so-called creative class), which is responsible, among other things, for the conceptual stage in innovative processes; This dimension is also related to motivating employees to cooperate and share knowledge in the conditions of ICTs (fast file transfer, monitoring of work progress online, etc.);
- financial – it is related, among other things, to cost reduction in innovative processes (free or low-cost technologies with high efficiency and reliability); Costs can also be reduced as a result of lowering employee errors and erroneous management decisions, as well as shortening the implementation of specific processes – this can have a significant impact on the price and availability of innovations in the market; The financial dimension is also related to enabling the company to achieve higher profits from innovative activities;
- market – is primarily concerned with increasing the company's ability to develop and implement the innovations expected by users and increasing the company's market share;
- infrastructural and technological – ICT infrastructure is being improved, which may affect the broadly understood quality of innovation and the quality of innovative processes, as well as may increase the effectiveness of innovation distribution (digital channels and digitized customer service);
- managerial and process – this dimension refers primarily to support management and owners in knowledge management and decision-making in the field of market analysis, developing a list of new functions/options for created innovations and shaping/stimulating the scalability of the business model, or in planning further adjustments in innovative processes; This dimension may also refer to the shortening of activities in innovative processes.

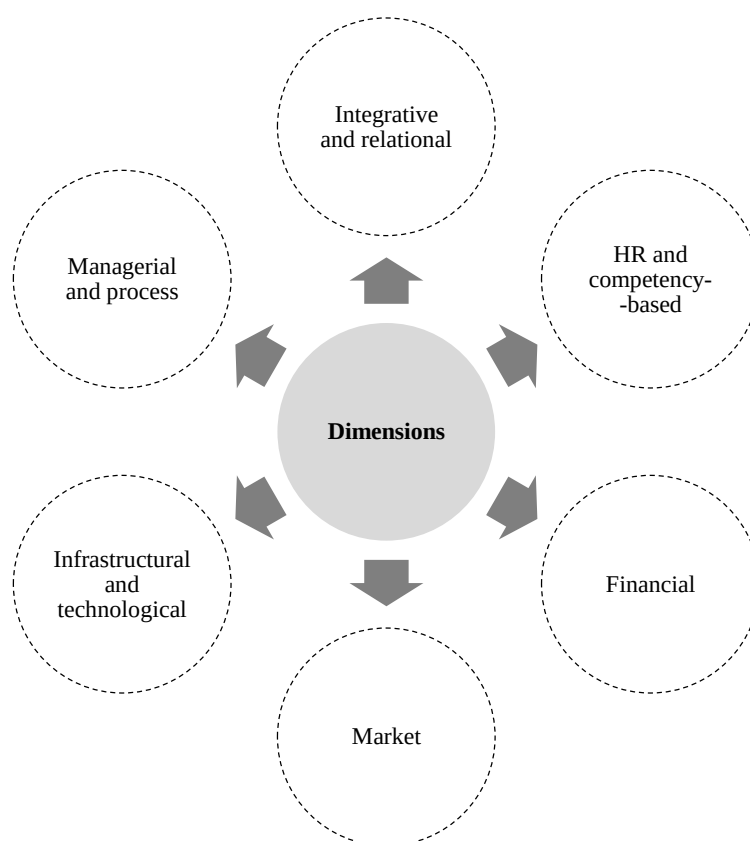


Figure 2. Dimensions of the impact of ICTs on an innovative enterprise.

Source: own elaboration.

Based on the content above, it can be inferred that ICTs can have a significant and beneficial impact on the innovative activities of enterprises and the outcomes they achieve. The use of ICTs itself should be of great importance in shaping innovative processes and providing them with the required and appropriate conditions (infrastructural, informational, process-related, etc.).

3. Methods

3.1. Research objective, questions, and hypotheses

The subject of the study is the general relationship between the importance and use of ICTs and their potential impact on the effects of innovative activities. The study highlights two main aspects: (1) the importance of the use of ICTs in the enterprise, and (2) the potential impact of the use of ICTs on the effects of innovative activities. In other words, the study aims to highlight the coexistence of the phenomena of importance and the use of ICTs, as well as their potential impact on achieving various business and managerial effects (Table 1).

Therefore, the main objective of the study is to estimate the relationship between the importance of the use of ICTs and their potential impact on the effects of innovative activities, as well as to estimate the level of the complexity: (1) of the potential impact of the use of ICTs on the effects of innovative activities, and (2) of the importance of the use of ICTs in the enterprise.

Three research questions were asked in the study:

[RQ–1] *What is the average level of the complexity of the potential impact of ICTs on the effects of innovative activities?*

[RQ–2] *What is the average level of the complexity of the importance of the use of ICTs in the enterprise?*

[RQ–3] *What is the relationship between the complexity of the importance of the use of ICTs in the enterprise and the potential impact of the use of these technologies on the effects of innovative activities?*

Justification for [RQ–1; RQ–2; RQ–3]: These questions do not directly refer to the research of other authors, as they focus on the “complexity” of the potential impact of ICTs on the effects of innovative activities and the complexity of the importance of ICTs’ use in the enterprise. As a rule, the authors explore the issue of the impact of ICTs on innovative activities and the general importance of ICTs in the implementation of processes and tasks, but do not expand the research to include the aforementioned “complexity” – which is the proposal of the author of this article and refers to both the importance of ICTs and their impact in various areas and aspects of innovative activities of enterprises. However, referring to the studies of García-Álvarez (2015), Cuevas-Vargas et al. (2016), Gërguri-Rashiti et al. (2017), and Jameel et al. (2017), it can be noted that ICT is usually of great importance in enterprises and has a fairly substantial impact on the activities of companies (e.g., innovative), mainly in terms of the efficiency of innovative processes, competitiveness, and market position of the company, shortening the time of product/innovation development and information resource management. In addition, in the context of the research questions above, the following studies are relevant: Jarmooka et al. (2020), who indicate that ICTs are essential in improving the management of information resources, including knowledge; Idota et al. (2021), who note that ICTs are necessary in the context of increasing management engagement and increasing the level of employee motivation; and Azam et al. (2024), who argue that ICTs are essential in improving the openness of the enterprise. Because ICTs are relatively important and can potentially have a beneficial and substantial impact on the effects of innovative activities, the study will attempt to estimate the level of the “complexity” of this importance and impact in the conditions of innovative enterprises operating in Poland.

The research hypotheses relating to [RQ–3] are as follows (Figure 3):

- [H–1] There is a strong and positive correlation between the complexity of the importance of the use of ICTs in the enterprise, and the potential impact of the use of these technologies on the effects of innovative activities.
- [H–2] There is a strong and positive correlation between the complexity of the importance of the use of ICTs in the enterprise, and the complexity of the potential impact of the use of these technologies on the effects of innovative activities.

Justification for [H–1; H–2]: These hypotheses, like the research questions above, do not directly refer to the research of other authors, as they focus on the “complexity” of the potential impact of the use of ICTs on the effects of innovative activities and the complexity of the importance of the use of ICTs in the enterprise. However, the basis for the hypotheses above is the research of Loukis et al. (2013) and Koraca (2021), which empirically show that there is usually a strong and positive relationship between the use of ICTs and the effects of business activities. The hypotheses [H–1; H–2] extend the research mentioned above to the specific functioning of innovative enterprises operating in Poland.

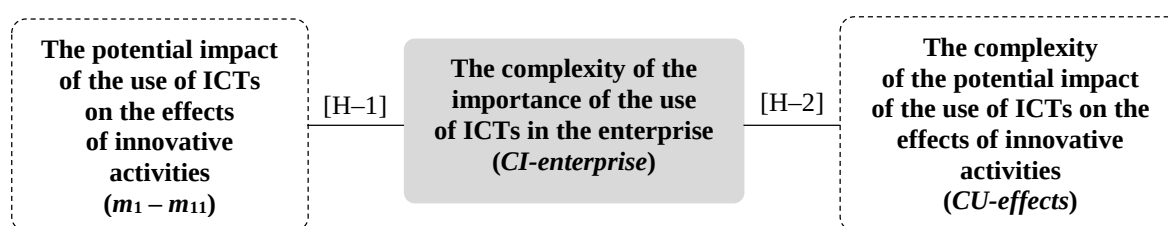


Figure 3. Research hypotheses.

Source: own elaboration.

At this point, it should be clearly noted that the study is not intended to determine the impact of the use of ICTs on the effects of innovative activities. The potential impact of ICT use is estimated by respondents using a 5-point scale (where “1” means “very low impact” and “5” means “very strong impact”) and reflects the position of owners or managers in innovative companies. In this way, the estimated impact serves as the basis for constructing one of the variables used in subsequent analyses, namely, the complexity of the potential impact of ICTs’ use on the effects of innovative activities (*CU-effects*) (1). The result of the analyses will be an estimate of the level of correlation (co-occurrence) between the specified processes, i.e., the importance of using ICTs in the enterprise and the potential impact of their use on the effects of innovative activities.

3.2. Scope of the study and research methods

The subjective, spatial, and temporal scope of the study was determined. The study was conducted on a random sample, using a stratified sampling method (Rószkiewicz, 2021). The numbering of PKD departments determined the layers. The respondents were business owners or managers responsible for computerization/digitization processes, innovative

processes, or project management. The survey covered only large enterprises (employing at least 250 people) operating in Poland in the most innovative sectors. The study focuses on this set of enterprises because they prioritize high quality in innovative processes, characterized by economies of scale in innovative activities, and do not exhibit fundamental resource limitations (technological, financial, and personnel) in implementing innovative processes and digitizing their activities. The selection of these sectors was made based on statistics published in the reports of the Polish Development Fund (Kolasa, 2021, 2024). Only one respondent from each randomized company was included in the research sample. A prerequisite was to answer “yes” to the screening question: *Have you successfully implemented at least ten innovations (in the form of a service, product, or project) for your customers in the past 5 years of your activity on the market?* The baseline study was conducted in December 2024. It covered the last five years of innovative activities by the companies selected for the research sample, i.e., the period from January 2020 to December 2024. The survey covered the area of 16 voivodeships in Poland.

The empirical study used an inductive approach primarily, which allows for the generalization of phenomena (Sułkowski, 2012; Dobrzycka, 2014; Wojciechowska, 2016). The study also considered elements of the deductive approach, mainly at the stage of querying domestic and foreign literature sources. This was the basis for the development of the CAWI questionnaire. At this point, it is worth emphasizing that the inductive approach played a leading role in the study (Bogdanienko, 1983; Piórkowska, 2021). The study also used methods of analysis and synthesis (Hajduk, 2012). Furthermore, it is essential that a narrative review method was used at the stage of querying the literature. The empirical method was a diagnostic survey (Karbownik, 2017) conducted using the CAWI survey. The technique of statistical analysis of quantitative data was also used (Apanowicz, 2005; Zaborek, 2009; Sudoł, 2012). The basic research and analytical tools were:

- CAWI questionnaire (contained: one screening question, the main part – nineteen detailed questions requiring respondents to evaluate metrics on a 5-point scale (“1” meant “very low importance/impact”, and “5” meant “very strong importance/impact”), and a metric – five questions);
- PS IMAGO PRO (ver. 10.0) software, and MS Excel.

The analytical methods and techniques that have been used to verify the research hypotheses are as follows:

- verification of the reliability of the 5-point scale for the specific questions (metrics) included in the survey – using Cronbach’s alpha coefficient (for each of the questions, this coefficient took a value above 0.6, i.e., the limit value);
- factor analysis using the principal component analysis method (PCA) – to develop composite indexes (*CU-effects* and *CI-enterprise*);
- Spearman’s rho correlation coefficient.

To complement the interpretation of the results and answer the research questions, basic descriptive statistics were used.

The basis for constructing two composite indexes, *CU-effects* (1) and *CI-enterprise* (2), was a list of processes and effects of innovative activities, assessed by respondents on a 5-point scale in terms of the importance or potential impact of ICTs. The list of these processes and effects is included in Table 1, which takes the form of the so-called detailed metrics required in PCA analysis. At this point, it should be clearly noted that this is not a comprehensive set of both the effects of innovative activities that may be potentially affected by ICTs, and the processes in which the use of ICTs is essential. The set of effects was developed mainly based on the following studies: García-Álvarez (2015), Cuevas-Vargas et al. (2016), Gërguri-Rashiti et al. (2017), Wang and Qi (2020), Zhu et al. (2021), Idota et al. (2021), and Azam et al. (2024). In turn, the set of processes was created primarily based on the following studies: Jarmooka et al. (2020), Wang and Qi (2020), Idota et al. (2021), Shirazi and Hajli (2021), Alam et al. (2022), Jagiełło (2024), and Łukasik and Zaskórski (2025). Both sets were aggregated – primarily to simplify the analysis, but also due to research limitations (research costs).

Table 1.

Detailed metrics included in the analysis

Detailed metrics	
Potential impact of the use of ICTs – effects	
<i>m</i> ₁	Reducing employee errors
<i>m</i> ₂	Increasing the level of specialization in the market
<i>m</i> ₃	Increasing the company's market share / Increasing the number of customers
<i>m</i> ₄	Increasing the number of innovations/new solutions/products/services developed
<i>m</i> ₅	Effective and planned implementation of the company's budget assumptions
<i>m</i> ₆	Increasing the company's financial liquidity
<i>m</i> ₇	Reducing the business's total cost of ownership
<i>m</i> ₈	Increasing profits
<i>m</i> ₉	Increasing the volume of sales of products/services
<i>m</i> ₁₀	Reducing the time spent on planning and preparing business processes
<i>m</i> ₁₁	Reducing the time to develop innovations/new solutions/products/services
The importance of the use of ICTs in the enterprise – processes	
<i>m</i> ₁	Providing the required data and information in innovative processes
<i>m</i> ₂	Ensuring continuity/sustainability of innovative processes
<i>m</i> ₃	Networking of innovative processes (openness to cooperation with external entities)
<i>m</i> ₄	Support for decision-making processes
<i>m</i> ₅	Support for data analysis in the company
<i>m</i> ₆	Support for market analysis
<i>m</i> ₇	Support for design processes
<i>m</i> ₈	Support for conceptual/creative processes

Source: own elaboration.

At this point, we will proceed to describe the methodology for constructing composite indexes, *CU-effects* (1), and *CI-enterprise* (2). The *CU-effects* index (the complexity of the potential impact of the use of ICTs on the effects of innovative activities) shows, in a simplified way, how many areas and to what extent ICTs can potentially influence the effects of innovative activities of enterprises. On the other hand, the *CI-enterprise* index (the complexity of the

importance of the use of ICTs in the enterprise) refers to how many processes and at what level ICTs can be important in the activities of innovative enterprises.

The study decided to use composite indexes because they enable (Nardo et al., 2005):

- conducting a holistic analysis;
- considering a relatively large number of the detailed metrics and grouping them into thematically coherent components;
- quantification and assessment of phenomena (which by their nature are complex and relatively difficult to quantify).

To verify the quality of the data, the reliability of the scale was analysed using Cronbach's alpha coefficient. For the complete list of meters (Table 1), the Cronbach's alpha coefficient was 0.864 for the *CU-effects* index and 0.802 for the *CI-enterprise* index. The methodological recommendations developed by the OECD (2008) were used in constructing both indexes. Stages have been completed (Nardo et al., 2005):

- determining the scope of measurement and the legitimacy of using a composite index;
- selection of the detailed metrics (m_i);
- evaluation of the quality of empirical data;
- assessment of the relationship between the detailed metrics;
- assigning component weights and aggregating them to a composite index.

Table 2.

Information about the data analysed and reliability statistics

		N	%
Observations	Included	260	100
	Excluded*	0	0
	Total	260	100
Index	Cronbach's alpha	Number of items	
<i>CU-effects</i>	0.864	11	
<i>CI-enterprise</i>	0.802	8	

Note. * Excluded by observations due to all variables in the analysis.

Source: own elaboration.

The results of implementing the first three stages are presented above. In evaluating the relationship between detailed metrics and the aggregation of components into composite indexes, the method of factor analysis, specifically principal component analysis (PCA), was employed (Hudrliková, 2013). To verify the correctness of the PCA analysis, the Kaiser-Meyer-Olkin (KMO) coefficient and Bartlett's sphericity test were used. The limit value of the KMO index is assumed to be between 0.5 and 0.7 (Williams et al., 2012). Bartlett's sphericity test indicated that hypotheses with uncorrelated coefficients can be rejected (significance level less than 0.001) (Table 3). Further analysis of PCA is justified and methodologically correct.

Table 3.*Kaiser-Mayer-Olkin and Bartlett's tests*

Index		<i>CU-effects</i>	<i>CI-enterprise</i>
KMO measure of sample adequacy		0.914	0.849
Bartlett's sphericity test	Approximate Chi-Square	845.721	469.773
	<i>df</i>	55	28
	Significance	<0.001	<0.001

Source: own elaboration.

In further analysis, the method of extracting principal components using Varimax rotation was employed. Factor analysis provided the basis for classifying the detailed metrics into a single component in both constructed indexes (Table 4).

The formula of the *CU-effects* index (the complexity of the potential impact of the use of ICTs on the effects of innovative activities) is as follows (it is an arithmetic mean) (1):

$$CU-effects = 1 \cdot C1 = 1 \cdot (m_1 + m_2 + m_3 + m_4 + m_5 + m_6 + m_7 + m_8 + m_9 + m_{10} + m_{11}) / 11. \quad (1)$$

And the formula of the *CI-enterprise* index (the complexity of the importance of the use of ICTs in the enterprise) is as follows (it is an arithmetic mean) (2) :

$$CI-enterprise = 1 \cdot C1 = 1 \cdot (m_1 + m_2 + m_3 + m_4 + m_5 + m_6 + m_7 + m_8) / 8. \quad (2)$$

Table 4.*Total variance explained*

Component	Initial eigenvalues			Sums of load squares after extraction		
	Total	% of variance	% cumulated	Total	% of variance	% cumulated
CU-effects						
C1	4.671	42.460	42.460	4.671	42.460	42.460
C2	0.924	8.404	50.864			
C3	0.825	7.501	58.364			
C4	0.757	6.881	65.246			
C5	0.650	5.910	71.156			
C6	0.621	5.645	76.801			
C7	0.595	5.405	82.206			
C8	0.556	5.056	87.262			
C9	0.522	4.741	92.003			
C10	0.478	4.346	96.349			
C11	0.402	3.651	100.000			
CI-enterprise						
C1	3.367	42.093	42.093	3.367	42.093	42.093
C2	0.870	10.874	52.967			
C3	0.794	9.928	62.895			
C4	0.701	8.761	71.656			
C5	0.653	8.162	79.818			
C6	0.628	7.849	87.667			
C7	0.567	7.094	94.761			
C8	0.419	5.239	100.000			

Note. The method of extracting the factors – principal components.

Source: own elaboration.

The following section of the article presents the specification of the research sample.

3.3. Description of the research sample

The size of the research sample ($N = 260$ enterprises) can be considered representative. The determination of the minimum sample size for 183 innovative enterprises was carried out based on the methodology proposed by Sopińska and Dziurski (2018). The population size was determined based on data published by the Statistics Poland (GUS, 2023a, 2023b), which were current at the time of survey design.

Referring to the first attribute of enterprises, it can be noted that in each of the ten layers of enterprises (designated by PKD departments), there were 10% of respondents:

- food production [Department No. 10], and beverages production [Department No. 11];
- manufacture of textile products [Department No. 13], and manufacture of clothing [Department No. 14];
- manufacture of chemicals and chemical products [Department No. 20];
- manufacture of basic pharmaceutical substances and medicinal products, and other pharmaceutical products [Department No. 21];
- manufacture of computers, electronic and optical products [Department No. 26], and manufacture of electrical equipment [Department No. 27];
- manufacture of motor vehicles, trailers and semi-trailers, excluding motorcycles [Department No. 29];
- warehousing and transport support services [Department No. 52];
- activities related to the production of films, video recordings, television programs, sound, and music recordings [Department No. 59];
- telecommunications [Department No. 61], and software and IT consultancy activities, and related activities [Department No. 62];
- insurance, reinsurance, and pension funds, excluding compulsory social insurance [Department No. 65].

Considering the age of the surveyed enterprises (i.e., the number of years of operation on the market), it is notable that the research sample is dominated by entities operating for 6 to 10 years (48.85%). On the other hand, enterprises operating for 11 to 15 years account for 27.30%, and those operating for over 15 years – 23.85%. Considering the criterion of the scale of innovative activities, it can be noted that the most significant percentage in the research sample is entities operating on a regional scale (1-8 voivodeships in Poland), at 38.85%, and on a national scale (9-16 voivodeships in Poland), at 30.38%. A large percentage of the sample is also represented by entities with an average annual turnover of at least PLN 6 million (52.70%), as well as in the range of PLN 3 to 6 million (41.15%). Considering the spatial distribution of the surveyed entities, it is notable that the most significant percentage of the sample consists of innovative enterprises located in the following voivodeships: Mazowieckie (19.23%), Dolnośląskie (10.38%), Śląskie (10.00%), and Małopolskie (8.85%).

4. Results

The analysis of the results obtained should begin with answering the first two research questions:

[RQ–1] *What is the average level of the complexity of the potential impact of ICTs on the effects of innovative activities?*

[RQ–2] *What is the average level of the complexity of the importance of the use of ICTs in the enterprise?*

For this purpose, composite indexes *CU-effects* (1) and *CI-enterprise* (2) have been developed.

The developed formulas of indexes (1) and (2) provided the basis for determining descriptive statistics (Table 5). The distribution of the values of both indexes is characterized by a relatively weak left-sided skewness, indicating that a slight majority of the values of these indexes (representing the average ratings of respondents) are higher than the mean. Because each of the detailed metrics included in the construction of both indexes (1) and (2) was evaluated on a 5-point scale, it can be assumed, to put it simply, that these indexes assume mean values at a moderately high level (*CU-effects* – 3.54; *CI-enterprise* – 3.49) – the median for the 5-point rating scale is at the level of 3.00. Thus, both the average level of the complexity of the potential impact of the use of ICTs on the effects of innovative activities, and the average level of the complexity of the importance of the use of ICTs in the enterprise, are at a moderately high level.

Table 5.
Descriptive statistics

Statistics	<i>CU-effects</i>	<i>CI-enterprise</i>
Mean	3.54	3.49
Median	3.45	3.50
Dominant	3.00*	3.00*
Standard deviation	0.644	0.639
Variance	0.414	0.409
Skewness	–0.022	–0.258
Kurtosis	0.561	1.640
Gap in value	3.91	3.75
Minimum value	1.09	1.25
Maximum value	5.00	5.00

Note. * There are many modal values. The lowest value is given.

Source: own elaboration.

On the other hand, the answer to the research question [RQ–3]: *What is the relationship between the complexity of the importance of the use of ICTs in the enterprise and the potential impact of the use of these technologies on the effects of innovative activities?*, requires verification of the [H–1] and [H–2] hypotheses. For this purpose, the values of Spearman's rho correlation coefficient were calculated (Table 6).

In the case of [H–1], the correlation values between the values of the *CI-enterprise* index and the values of the potential impact of the use of ICTs on individual effects of innovative activities were determined (in this case, reference was made to eleven effects) (Table 6). In all cases, a moderate or moderately weak positive, statistically significant correlation was noted. Therefore, the [H–1] hypothesis must be falsified.

In turn, for verification [H–2], the values of the Spearman's rho correlation coefficient between the values of the *CI-enterprise* and *CU-effects* indexes were determined (Table 6). In this case, the value of the correlation coefficient was 0.586, indicating a moderately strong correlation (and statistically significant). However, the [H–2] hypothesis must be falsified.

Table 6.

Spearman's rho correlations

Metrics	Potential impact of the use of ICTs – effects		CI-enterprise
m_1	Reducing employee errors	Correlation coefficient	0.379*
		Significance (bilateral)	<0.001
m_2	Increasing the level of specialization in the market	Correlation coefficient	0.488*
		Significance (bilateral)	<0.001
m_3	Increasing the company’s market share / Increasing the number of customers	Correlation coefficient	0.394*
		Significance (bilateral)	<0.001
m_4	Increasing the number of innovations/new solutions/products/services developed	Correlation coefficient	0.322*
		Significance (bilateral)	<0.001
m_5	Effective and planned implementation of the company’s budget assumptions	Correlation coefficient	0.339*
		Significance (bilateral)	<0.001
m_6	Increasing the company’s financial liquidity	Correlation coefficient	0.323*
		Significance (bilateral)	<0.001
m_7	Reducing the business’s total cost of ownership	Correlation coefficient	0.345*
		Significance (bilateral)	<0.001
m_8	Increasing profits	Correlation coefficient	0.301*
		Significance (bilateral)	<0.001
m_9	Increasing the volume of sales of products/services	Correlation coefficient	0.347*
		Significance (bilateral)	<0.001
m_{10}	Reducing the time spent on planning and preparing business processes	Correlation coefficient	0.449*
		Significance (bilateral)	<0.001
m_{11}	Reducing the time to develop innovations/new solutions/products/services	Correlation coefficient	0.445*
		Significance (bilateral)	<0.001
CU-effects		Correlation coefficient	0.586*
		Significance (bilateral)	<0.001

Note. * Correlation significant at 0.01 (bilateral).

Source: own elaboration.

Referring more broadly to the research question [RQ-3], it should be noted that this relationship is, in general, positive and at a moderate level. This can be interpreted in such a way that the higher the complexity of the importance of the use of ICTs in the enterprise (assessed by the respondents), the higher the values of the potential impact of the use of these technologies on the effects of innovative activities.

5. Discussion and Conclusions

The research conducted has shown that, in principle, the increase in the complexity of the importance of ICTs in an enterprise corresponds to the rise in the complexity of the potential impact of the use of these technologies on the effects of innovative activities, as well as an increase in the value of the potential impact of the use of ICTs on specific (single) effects of innovative activities. The results obtained confirm the positively verified hypotheses put forward in the studies of Loukis et al. (2013) and Koraca (2021), which indicated that there is usually a strong and positive relationship between the use of ICTs and the effects of enterprises' activities. Of course, hypotheses [H-1; H-2] verified in this study are not entirely identical to those verified by Loukis et al. (2013) and Koraca (2021). However, their message is similar.

The research results above should be considered a favourable situation, mainly from the perspective of innovative companies' investments in various modern ICTs, and thus striving for a higher quality of innovative processes and innovations. However, individual companies should estimate the value of this dependency on their own and consider it in the broader context of the market, technological, social, and other conditions in which they operate or will continue to operate.

The results obtained are also consistent with the studies of García-Álvarez (2015), Cuevas-Vargas et al. (2016), Görguri-Rashiti et al. (2017), Jameel et al. (2017), Jarmooka et al. (2020), and Azam et al. (2024). They confirm that ICTs are generally of moderate importance in enterprises and have a moderately high impact on innovative activities (reference to the [RQ-1; RQ-2] research questions). Examples include increasing the efficiency of innovative processes, enhancing the level of competitiveness and openness within the company, reducing product development time, and effectively managing information resources.

Summarizing the research, it can be inferred that the use of ICTs in innovative enterprises is a significant and well-justified activity in the current socio-economic environment. ICTs enable, among other things, the operation in global circumstances while reducing the costs of developing innovative processes, facilitating the hyper-scalability of business models, improving communication within enterprises, as well as between the company and external stakeholders, and supporting the reduction of task completion time. There are many potential benefits resulting from the implementation and use of ICTs in innovative activities. However, to achieve such effects, attention should be paid to the general importance of ICTs within the company and in individual processes that support and dynamize innovative activities. Such processes include, among others, providing the required data and information, networking innovative processes, supporting decision-making processes, conducting data and market analysis, and supporting design processes. The level of awareness among owners of innovative companies and executives about the importance of ICTs within their companies is of great importance. The implementation of various solutions available on the market does not always

result in satisfactory support for innovative activities and measurable benefits, such as shortening the time to action, reducing costs, etc. It may be crucial to assign an appropriate role to these solutions during the planning stage of ICTs' implementation. Then it will be easier to estimate the overall relationship between the use of ICTs and the results obtained. Summarizing the considerations above, it can be assumed that companies should pay more attention to the benefits that can result from implementing information and communication technologies in innovative processes. Companies should estimate the potential impact of ICTs on innovative processes and develop their own procedures in this area, which can lead to increased efficiency and effectiveness in implementing various ICT solutions.

At this point, it is worth noting that the aim of the article was not to fully generalize the conclusions for the population of innovative enterprises operating in Poland. The set of these entities is diverse, and the research sample did not consider the proportions between individual attributes of enterprises in the population. Moreover, the analyses were based on the opinions of respondents, which could be subject to errors and bias in the assessment. The aim of the study was primarily to assess the overall situation regarding the importance of ICTs in innovative enterprises in comparison with their potential impact on the effects of innovative activities.

Considering the content above, it can be assumed that the directions of further research should focus on identifying the cause-and-effect relationships between the use of various ICT technologies, systems, and tools, and the effects of innovative activities in Polish innovative enterprises.

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ATTITUDE TO PATRIOTISM AND DEFENSE OF YOUTH ON THE EXAMPLE OF STUDENTS OF UNIFORMED CLASSES OF THE WEST POMERANIAN PROVINCE

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Purpose: The article presents a comprehensive study of the attitudes of bathers within identifying potential challenges and opportunities as well as recommendations for the future of educational programs on patriotism and defense in Poland.

Design/methodology/approach: The study employs literature analysis, tabular comparisons, and questionnaires of bathers. The approach for the research was based on a desktop evaluation of accessible information from international and national sources. The qualitative data acquired from self-research was used in the statistical analysis. The research group had 277 respondents, and the research was scheduled for May-June 2023.

Findings: Parallels exist in governance and policy alignment, while disparities are evident in economic development and sectoral priorities. These findings offer a nuanced understanding of shared traits and distinct differences shaping the business landscapes and economic paths of these Central European nations.

Research limitations/implications: The research has limitations, such as its specific timeframe and omitted variables.

Practical implications: Practical implications extend to i.a. the need of implementing effective prevention programs (level 1 prevention) of safe behavior on the water and include this from the municipal level through the regional and national levels and introducing of a multi-year, unified national program of education and behavior in water areas, will increase the swimming skills of all age groups and reduce drowning.

Social implications: The study suggests indicating systemic changes in educational programs. Referring to the data presented in a broader perspective, it should be assumed that the appearance of various forms of military activity in the educational process can affect the attitude of the younger generation to military service. The determination of the scope and forms of implementation of defense education should be considered by specialists. The study also showed that among students the individualistic attitude leads primacy over the collective one. Research outcomes also suggest also a kind of dualism among respondents falling between an individualistic attitude and a team-oriented attitude, which, especially in an emergency, can result in unpredictable behavior.

Originality/value: The uniqueness of this research lies in the development of a technique to survey attitudes toward patriotism and defense among young people. The research findings are applicable to both academic discourse and practical implementations, providing unique insights to foster collaboration and development within policymakers' institutions and organizations.

Keywords: Patriotism, defense, youth, education, educational programs.

Category of the paper: research paper.

1. Introduction

The variety of approaches to the essence of patriotism and defense makes these terms difficult to define. In literature, there is a discussion not only about defining the concepts of patriotism and defense, but also about patriotic and defensive attitudes.

Two approaches to the definition of patriotism can be noted among researchers. The first boils down to "(...) citing and deconstructing its dictionary meaning and etymology (after Marzęcki, 2019, p. 10), as well as explanations based on the description of historically observed attitudes of individuals and social groups (...)". The second identifies patriotism with the emotional state to one's country (attachment, loyalty, pride, love) and the enumeration of its attributes, such as culture, values, territory, system, history, government, people (Theiss-Morse, 2009, p. 23). In this sense, patriotism makes it possible for citizens to self-categorize into a specific social group and is described as one of the most important forms of attachment to a social group in the modern World (Marzęcki, 2019). In this case, researchers of the subject have pointed out the functional dualism of such identification with the nation, where "pseudo-patriotism" (conformism of prevailing attitudes, treating other nations as "foreign") and "authentic patriotism" (attachment to the country, nation, national values but based on critical reflection) are specified (Tajfel, 1974). Also, studies of Poles' understanding of the term "patriotism" (*Rozumienie ...*, 2008) indicate different ways in which respondents interpret it. There are also various attempts at its typology (Cf. Burgoński, 2008). Realizing the difference in defining the concept in question both among researchers and in social practice and bearing in mind that from the perspective of the research results presented in this paper, the way patriotism was understood was not important (Table 2), authors decided not to define it explicitly.

Related to the concept of patriotism is the question of the defense attitudes of citizens, the formation of which provides the basis for social unity, sovereignty, independence and territorial integrity (...)" (Malinski, 2016, p. 192). The defense consciousness of society thus has the dimension of duty to the Fatherland, as mentioned in Article 5 of the Polish Constitution, which states that "The duty of a Polish citizen is loyalty to the Republic of Poland and concern for the common good". Thus, the formation of patriotic and defensive attitudes will affect the existence of the nation and the state with the ability and effectiveness to defend them (Malinski,

2016). For example, Polish surveys show that "readiness to fight and give one's life for the Fatherland" is mentioned by 88% of Poles as one of the manifestations of patriotism (Patriotyzm..., 2018, pp. 7-8).

It needs to be underlined, that of fundamental importance in the development of the above attitudes is patriotic education and defense, the main goals of which are: forming a bond with the Fatherland and civic awareness, developing respect for pro-social attitudes and the common good, forming respect for one's own country (Belowski, 2018, p. 105). It is also not insignificant to form a sense of participation in the life of the community contributing to the growth of the level of social capital of the community and society and the growth of social participation (Zakrzewska, 2024). Thus, the duration as well as the quality of patriotic and defense education will determine the patriotic and defense attitudes of young people. This is particularly important in the present times, when values are losing their meaning and patriotism is becoming a platitude in the eyes of the younger generation. Highly motivated and aware of patriotic-defense issues, young people can influence the defense of the state through their attitude and behavior (Marzecki, 2019).

The purpose of this article is an attempt to present the attitude to patriotism and defense of youth in Poland on the example of students of uniformed classes considering the research conducted by the academics of the University of Szczecin on a group of 277 students in May and June 2023.

2. Development of the functioning of defense education of schoolchildren in Poland – historical background

The functioning of defense education for schoolchildren in Poland began after gaining independence in 1918. Between 1918 and 1939, it manifested itself in two areas of preparing young people for military service. The first area of activity was patriotic upbringing combined with the development of the expected civic attitudes of the reborn Polish state, and the second element was practical military preparation, particularly physical exercises combined with elements of drill, shooting and topography. Activities in this area were under the supervision and control of the State Office of Physical Education and Military Preparedness (Wojtycza, 2012).

Defense education of schoolchildren from 1945 to 1990 was subordinated to the needs of the armed forces and the functioning of Poland within the Warsaw Soviet Pact bloc of countries. These activities were carried out as part of the subject of military training and, since 1967, defensive training. The defense preparation of society was also carried out by organizations such as the National Defense League, the Polish Scouting Association, which in their statutory activities also realized elements of military preparation of youth. During this period, there were

no other forms of defense preparation in secondary schools. The exception were military high schools, which were located within the structure of the Ministry of Defense (Zaczek-Zaczyński, 2020).

The process of political change in Poland after 1989 also influenced the departure of mass youth preparation for military service. After Poland access to NATO in 1999, the issue of changing the approach to defense education for schoolchildren also evolved. At the beginning of the 21st century, the subject of defensive training was replaced in 2009 by so-called Education for Security, which did not include curricular content on military activities such as shooting and topography.

The formation of uniformed classes after 2000 was primarily associated with grassroots initiatives of schools and teachers, and the functioning of legal formula provided a variety of solutions at the level of secondary education.

Uniformed classes (military, police, firefighters and border guards) have been operating in Poland for the past twenty years on the basis of educational regulations on innovative activities of schools or pedagogical experiments and implemented various programs.

This form of defense education allows not only to acquire personnel resources for the professional armed forces, but also to prepare personnel reserves for the defense system, including the non-military subsystem. An essential element of this is the voluntary nature of this form of defense education for Polish youth. Not without significance here is the substantive and financial support of the state implemented at the level of the Ministry of Defense, as well as the practical participation of patron military units in the defense education of young people.

Defensive education of Polish society in the 21st century is a system of education, which refers in particular to defensive education in schools. Activities carried out in uniformed classes include not only elements of post-defense preparation, i.e. acquisition of shooting skills, but also behavior in the event of other dangers resulting from warfare or disasters, such as first aid, rescue and humanitarian aid. An element of this education are also activities aimed at building civic and patriotic attitudes in young people. By implementing defense education in uniformed classes, a lot of attention is also paid to bringing closer the problems of conflicts and international law, as well as the activities of organizations that stabilize peace in the world.

Currently, security is not a matter that concerns only the operation of the armed forces, but affects society as a whole. Armed conflicts are not only military in nature and take place on many levels, which practically affect every citizen, especially civilians who are not directly involved in combat.

The implementation of education of young people in uniformed classes in the field of security and defense is to build awareness about threats and allows them to acquire skills to respond to these threats. It also makes it possible to be sure that in the event of an external threat, e.g. war, attack, a defensively prepared society will know how and what to do to counter the aggressor.

Uniformed class education programs within school facilities are regional in scope and are linked to institutional support from entities such as the Polish Armed Forces under the Certified Military Uniformed Classes (CWKM) program (Certyfikowane..., 2023). This has been in operation since 2017 and consists of providing uniform military training in high schools and preparing volunteers for military service. In addition to the core curriculum, students also follow a program of "military education" - These totals 185 hours of theoretical and practical classes (Serwis..., 2024).

Starting in 2020, secondary schools can apply to the Minister of National Defense for permission to establish military preparation branches (OPW). This possibility was provided by an amendment to the Education Law and the Law on Financing Educational Tasks, on the basis of which military preparation branches will be created in public and non-public secondary schools. The first branches of military preparation were launched in the 2020/2021 school year, and successively every year more will be created. The introduction of military preparation branches affiliated with the Ministry of Defense does not interfere with the possibility of further operation of classes with a military profile and other uniformed specialties, based on pedagogical innovations and experiments implemented by schools.

3. Research outcomes

As mentioned before, the purpose of the article was to study the attitudes towards patriotism and defense of uniformed classes, which, due to their characteristics, are particularly oriented towards them.

The research was conducted in May-June 2023 among students of uniformed classes from 10 secondary schools located in 7 counties of the West Pomeranian Voivodeship participating in the project of educational reunion of uniformed classes organized by the University of Szczecin and the Marshal's Office of the West Pomeranian Voivodeship. The students who participated in the study were: 7th High School in Szczecin, West Pomeranian Center for Maritime and Polytechnic Education in Szczecin, High School in Chojna (Gryfino County), I High School in Gryfino (Gryfino County), II High School in Stargard, High School in Kalisz Pomorski (Stargard County), Private High School in Białogard, High School in Gościn (Kolobrzeg County), High School in Trzebiatów (Gryfice County), 1st High School in Goleniów (Goleniów County).

A total of 277 uniformed class students were surveyed, of whom 146 (52.71%) are male, 128 (46.21%) are female. 3 respondents (1.08%) did not specify their gender. Most students, 184 (66.43%), are urban residents. Among the respondents, representatives of military profile classes dominated (131 respondents - 47.29%). The second in number were students of police classes (88 respondents - 31.77%), and the third were firefighting classes (17 respondents -

6.14%). The other category included 37 respondents (13.36%). Most respondents (189 - 68.23%) came from families with uniform traditions¹.

Respondents were asked to identify what they consider to be the most important dangers that may affect Poland in the nearest future (Table 1).

Table 1.

Respondents' opinions on the most serious threats to Poland's security in the nearest future

Selection option	N	%
International conflicts	198	71.48
Aggression from other countries	201	72.56
Terrorism	96	34.66
Organized crime	59	21.30
Corruption	77	27.80
Financial crises	146	52.71
Loss of jobs	85	30.69
Climate change	80	28.88
Natural disasters	75	27.08
I see no significant threats to Poland's security	8	2.89
Another answer	1	0.36
Total:	835	*301.44

* Data does not sup up to 100% because respondents were allowed to indicate more than one answer.

Source: own research.

In first place, the surveyed students pay attention to aggression by other countries (201 respondents - 72.56%) and international conflicts (198 respondents - 71.48%). The current war in Ukraine seems to have a strong influence on students' choices. Another important threat cited by students is financial crises (146 respondents - 52.71%). They see terrorism as a lesser threat (96 respondents - 34.66%). Loss of jobs worries 85 respondents (30.69%), and climate change worries 80 respondents (28.88%). Corruption (77 respondents - 27.8%) and natural disasters (75 respondents - 27.08%) had similar numbers of indications. Organized crime as a threat is listed by 59 respondents (21.30%). The fewest respondents do not see threats to Poland's security. They account for only 2, 89% of respondents (8 respondents). It seems that the mentioned order of indicating threats to security is not related to the specifics of the uniformed classes and is determined by the present issues. A particular influence on these opinions seems to be exerted by the ongoing armed conflict beyond Poland's eastern border armed conflict.

Respondents were also asked about their attitudes toward patriotism (Table 2).

¹ None of the analyzed characteristics of the respondents showed a statistically significant correlation and, therefore, were not included in further analysis.

Table 2.*Respondents' opinions on the statement "Patriotism is important"*

Selection option	N	%
I completely agree	148	53.43
I rather agree	104	37.55
I rather disagree	3	1.08
I completely disagree	1	0.36
I have no opinion	20	7.22
No data available	1	0.36
Total:	277	100.00

Source: own research.

For most respondents, patriotism is an important value. 252 students (90.98%) define their attitude to this value in this way (*completely agree* - 148 respondents or 53.43%; *rather agree* - 104 respondents or 37.55%). This figure is similar to the indications obtained in the uniformed classes (Urych, 2018, p. 151) in which 94% of students express interest in the values (85%, *to a great extent*, 9% *to a small extent*), as well as to the results of CBOS in 2018, in which 88% of respondents expressed themselves in a similar manner (39.00% definitely consider themselves patriots, 49.00% rather yes) (*Patriotyzm...*, 2018, p. 6), and definitely higher than the results of the November 2022 survey (*Patriotyzm po...*, 2022), in which 71% of Poles described themselves as patriots (48.00% definitely consider themselves patriots, and 23.00% rather yes). Thus, it can be concluded that membership in uniformed classes does not modify patriotic attitudes. It is merely an expression of the pro-social attitude of the students who were surveyed, which has its roots in Polish culture.

The attitudes of uniformed class students toward military service as an important component of national security were also examined (Table 3).

Table 3.*Respondents' opinions on the importance of military service to maintain security in Poland*

Selection option	N	%
Very important	212	76.53
Important	56	20.22
Of little importance	3	1.08
Never mind	-	-
No data available	6	2.17
Total:	277	100.00

Source: own research.

268 respondents (96.75%) consider it an important element (very important - 212 students i.e. 76.53%; important - 56 respondents i.e. 20.22%). These views, especially in the context of the threats mentioned by the respondents (Table 1), are obvious in nature. After all, the military is one of the most important elements of security. Since most students raise the importance of military service, it can be assumed that the characteristics of the respondents do not affect their opinions. At the same time, it should be remembered that the very membership of a uniformed class means that we are dealing with a certain type of students. In their educational process, various forms of military activity appear more than in other types of classes. The result is that

they are more involved in the defense sphere than the average citizen (*Polacy o...*, 2023). An additional factor reinforcing the discussed perception of the importance of military service is the fact that respondents choosing education in uniformed classes indicate that they associate their professional future with the military², and thus have a personal interest in emphasizing the importance of military service.

Respondents were asked to express their opinion on the importance of military service for peace in Poland (Table 4).

Table 4.

Respondents' opinions on the importance of military service for peacekeeping in Poland

Selection option	N	%
Very important	182	65.70
Important	78	28.16
Of little importance	7	2.53
Never mind	2	0.72
No data available	8	2.89
Total:	277	100.00

Source: own research.

260 students (93.86%) believe that military service is an important element in maintaining peace in Poland. This indication basically coincides with students' opinions on the importance of military service in maintaining security in Poland (Table 3). It seems that the two concepts are combined by students.

The study attempted to determine which individualistic or collectivistic values are placed first by students in uniformed classes (Table 5).

Table 5.

Respondents' opinions on the statement "National security is more important than privacy"

Selection option	N	%
I completely agree	22	7.94
I rather agree	85	30.69
I rather disagree	93	33.57
I completely disagree	28	10.11
I have no opinion	45	16.25
No data available	4	1.44
Total:	277	100.00

Source: own research.

107 students (38.63%: 7.94% - *completely agree* and 30.69% - *rather agree*) recognize the primacy of national security over the individual value of guaranteeing a sense of privacy. Slightly more respondents, 18 students (5.05%), believe the opposite (43.68%: 33.57% - *rather disagree* and 10.11% - *completely disagree*). Thus, it can be concluded that at this level of education, there is a slight predominance of those who put personal values above national values. Similar results were obtained in surveys conducted among students of military classes

² In the surveys discussed within this paper, as many as 67.2% of students in uniformed classes indicated that they associate their future with these services (*study in security-related fields* 23.47%; *work in uniformed services* 24.19%; *professional military service*, 19.86%).

(Urych, 2018, p. 169), who valued *freedom (personal independence, freedom of choice)* more than *national security (security from attack)*. At this point, one should wonder whether this tendency is not the result of the peculiarities of the developmental period in which the respondents find themselves. It is characterized, among other things, by a greater focus on selfish than pro-social motivation factors (Brzezińska et al., 2016; Czerwińska-Jaśkiewicz, 2015; Oleszkowicz, Senejko, 2011).

Attempts were made, also, to determine which element is more important to respondents - the national or state factor (Table 6).

Table 6.

Opinions on the statement "National security is more important than citizens' freedoms"

Selection option	N	%
I completely agree	22	7.94
I rather agree	74	26.71
I rather disagree	86	31.05
I completely disagree	40	14.44
I have no opinion	46	16.61
No data available	9	3.25
Total:	277	100.00

Source: own research.

Security is not as important to the students surveyed as civil liberties. 126 students (45.49%) think so. In contrast, 96 respondents (34.65%) hold the opposite view. This may indicate the primacy of state values over national values, as evidenced by young people's attachment to civic values. Civil liberties may also be associated in the minds of respondents with the right to personal self-determination, which is particularly important to them during this period of development.

It was also examined which values, traditionally attributed to uniformed services, are most important to students (Table 7).

Table 7.

Opinions on values important to uniformed services

Selection option	N	%	Rank
Loyalty	189	68.23	III
Obedience	94	33.94	VIII
Courage	241	87.00	I
Determination	137	49.46	VI
Integrity	172	62.09	V
Integrity	78	28.16	IX
Collaboration	183	66.06	IV
Ability to work in a team	198	71.48	II
Empathy	59	21.30	X
Concern for others	132	47.65	VII
Total:	1483	*535.38	-

* Data do not add up to 100% because respondents were allowed to indicate more than one answer.

Source: own research.

For students, courage is the most important value (241 students - 87.00%). Next is the ability to work in a team (198 students - 71.48%). The next indication is loyalty (189 people - 68.23%), cooperation (183 students - 66.06%) and honesty (172 people - 62.09%). Slightly fewer indications are determination (137 people - 49.46%) and concern for others (132 people - 47.65%). The least indications were obedience (94 people - 33.94%), integrity (78 people - 28.16%) and empathy (59 people - 21.30%). It can be concluded that, except for one personal trait (courage), values of a collective nature (ability to work in a team, cooperation, loyalty) dominate. They have a rather "traditional" character, which is, so to speak, inscribed in the image of the uniformed services. These features are currently regulated by the Ordinance of the Minister of Defense of Republic of Poland (*Rozporządzenie...*, 2015, p. 1; *Rozporządzenie...*, 2024, p. 2). At the same time, it should be remembered that nowadays it is considered that the cohesion of groups belonging to the category of uniformed services is a very important aspect of its effective functioning (Shils, Janowitz, 1948; Griffith, 2007; MacCoun, Hix, 2010; *Cohesion...*, 1993; Siebold, 2011; King, 2013). It is understood that such a level of integration of group members that allows them to sustain their commitment to each other, the organization and the tasks carried out (Henderson, 1985). Its manifestation is the convergence of the daily goals of an individual member with those of the group, and a sense of strong bonding and willingness to support each other, as well as loyalty and willingness to make the highest sacrifices for members of one's own team. References to the role of empathy in the uniformed services in different situational contexts can be found in the literature (Cutright, 2022; Stone, 2018). In this context, concern for others and empathy should be valued values among uniformed class students. Meanwhile, they are mentioned by respondents at seventh (concern for others 47% of indications) and empathy at tenth place (empathy 21.30%). It is noteworthy that in the hierarchy of values important to the uniformed services, the trait that is inseparable from the military is *obedience* is only in the eighth position (33.94%). It seems that such a low position of this trait among students of uniformed classes may indirectly confirm the validity of earlier statements (Table 5) that the age of the surveyed young people, may have an impact on the opinions presented by them.

4. Conclusions and findings

Analysis of the survey results allows us to conclude that participation in uniformed classes does not affect perceptions of security threats (Table 1). It seems that the factor influencing students' opinions is the existing socio-political and geopolitical situation in Europe - particularly the ongoing war in Ukraine. The nature of the classes in question also modifies students' patriotic attitudes to a small extent (Table 2) - they are more an expression of the culture of the collective than an effect of the specifics of the educational process in these units.

On the other hand, learning in uniformed units highly determines respondents' opinions on military service (Tables 3 and 4). **Therefore, it should be concluded that the programmatic training dedicated to uniformed classes prepared jointly by the Ministry of Education with the Polish Armed Forces brings the expected and contributes to the growth of post-defense awareness of young people.** Referring to the data presented in a broader perspective, it should be assumed that the appearance of various forms of military activity in the educational process can affect the attitude of the younger generation to military service. Of course, the determination of the scope and forms of implementation of defense education should be considered by specialists. The study also showed (Tables 5, 6) that among students the individualistic attitude leads primacy over the collective one. Admittedly, this attitude may be due to the developmental age of the students surveyed, but nevertheless, placing greater emphasis on pro-social elements in the educational process may contribute to an increase in the importance of elements of a communal nature among youth. This is an important aspect of the activities of the uniformed services, since readiness to provide support in various urgent situations is the primary goal of their activities. Respondents consider courage, teamwork, loyalty cooperation and honesty as the most important values (Table 7) catalyzing attitudes that foster social capital, participation and social cohesion. Consideration of the values from the perspective of the effectiveness of dispatch groups indicates that they are dominated by "technically" important elements for the efficient operation of services (*courage* - 1st place; *teamwork skills* - 2nd place; *loyalty* - 3rd place). Less important are those of a communal nature, shaping social relations (*integrity* - 9th place; *empathy* - 10th place). Empathy makes it possible to better understand the intentions of individual team members, which increases the efficiency of their work. It also allows you to empathize with the situation of the injured, and thus better respond to their needs. At the same time, it should be remembered that the nature of the activities of the uniformed services is not only related to direct intervention in situations, but also to preventive activities, which are related to the ability to interact with people from different social backgrounds. In such direct contacts, the possession of the two qualities mentioned above seems essential. Therefore, combining the two will increase the effectiveness of the teams' activities. Thus, it would be good for the educational program of uniformed classes to include such activities that consider both components simultaneously.

In summary, the results obtained indicate that the defense education program is quite effective, especially with regard to students' attitudes toward military service. This differentiates them from the general Polish population (*Polacy o...*, 2023) and this suggests that the introduction of various forms of defense education at school may be a way to change the opinion of Poles on the issue in question. At the same time, it seems that the programs implemented in uniformed classes do not fully meet their assumptions regarding "building civic and patriotic attitudes" since the opinions expressed by the respondents do not differ substantially from the general population. From this perspective, two scenarios of behavior can be adopted. The first of a non-distinctive nature, assumes that graduates of uniformed schools are supposed to present

a “general” state of the society in which they function - this allows them to better understand it and thus act more effectively in it. In the second, it would have to be assumed that uniformed services, are role models for the social environment in which they function. From this perspective, the assumptions implemented by the programs in the uniformed classes are insufficient and need to be corrected. In addition, the data suggests a kind of dualism among respondents falling between an individualistic attitude (Table 5) and a team-oriented attitude (Table 7), which, especially in an emergency, can result in unpredictable behavior. It is worth deepening this research area and from this perspective, looking at the educational programs of uniformed classes.

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EFFICIENCY OF THE VENTURE CAPITAL AND PRIVATE EQUITY BACKED IPO ON THE WARSAW STOCK EXCHANGE

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Purpose: The main goal of this paper is to examine 42 VC and PE backed IPOs and their return on equity indicator before and after IPO in the period of 2013-2023 on the Warsaw Stock Exchanges.

Design/methodology/approach: To confirm the statistical significance of the results regarding the behavior of the return on equity before and after the IPO process, a paired sample Student's t-test was conducted. For this purpose, a comparison was made between the ROE values obtained in the period between year n_{-1} and year n_{+1} for VC and PE backed IPOs.

Findings: Analyzing the results, it can be concluded that the differences in the return on equity levels within the examined group of companies are statistically significant. The ROE levels in the analyzed firms are higher before their introduction to the public market compared to the period following their stock market debut.

Research limitations/implications: Venture capital and private equity firms have played a vital role in the creation of public corporations. Its Initial Public Offerings (IPO) offers on the stock markets are well documented in literature. IPOs emerge when companies decide to enter the equity market by selling their stock to the public. It is widely acknowledged that IPO are subjected to many different research analyses. One of them is indicator of return on equity. This paper analyses the long run performance of Initial Public Offerings that are backed by venture capital or private equity sponsor in terms of return on equity indicator. Despite the large increase in investments and the concomitant increase in academic and practitioner literature, the historical performance of both segments remains controversial. This is due to the uneven disclosure of private equity returns and questions about the quality of the available private equity data. However, despite the extensive literature attempting to explain many different anomalies, there still has been no satisfactory answer to the causes of VC and PE backed IPO performance.

Originality/value: There is no such research conducted on WSE on VC/PE backed IPOs.

Keywords: VC and PE backed IPO, ROE performance, Venture capital investments.

Category of the paper: Choose one or two of the possibilities.

1. Introduction

The concept of private equity (PE) and venture capital (VC) represents a relatively new term for high-risk investments that have historically been carried out by various entities. Many authors describe these as medium or long-term investments in high-risk ventures, which are combined with managerial support. The term "venture capital" is sometimes replaced with "risk capital" and is considered one of the instruments of the capital market. Literally translated, it refers to equity capital invested in a risky venture. Venture capital is capital invested in companies that are in the early stages of development or are just beginning to enter the market. All actions taken by the fund and the entrepreneur aim to achieve above-average company value growth within a set time frame. The increase in enterprise value serves as a crucial source of capital for newly established small businesses, where the risk is significantly higher than in other types of private equity investments, which are typically directed at companies in more advanced stages of development. The core function of private equity and venture capital funds involves identifying, financing, and actively supporting young and innovative projects that demonstrate rapid value growth potential. The role of these funds also includes acting as intermediaries between capital investors and portfolio companies, in which the funds invest the capital raised from investors after conducting thorough analyses. Another important responsibility of fund managers is to ensure professional selection of promising investment projects. Private equity and venture capital represent medium- to long-term capital engaged in equity stakes of enterprises, jointly managed with a professional financial intermediary – the funds themselves. These companies are undergoing radical changes driven by rapid development, which is expected to result in above-average returns, although these investments also carry risks borne by the investor.

The most important characteristics of PE/VC funds include:

- Seeking non-public equity companies with high potential for market value growth.
- Investing capital and actively participating in company management to enable effective business development.
- Selling owned shares or equity interests to achieve specified capital gains.

There are numerous other definitions describing the nature and characteristics of venture capital and private equity fund operations. In the United States, such funds are represented by the National Venture Capital Association (NVCA), which defines venture capital as high-risk capital that transforms innovative ideas and basic research into products and services that change the world. It is about building high-growth companies from the ground up. Venture capital is a unique asset class for institutional investors. Venture capitalists form partnerships with pension funds, endowments, foundations, and other entities to make risky, long-term capital investments in innovative young companies. According to *Invest Europe*, the organization that brings together European PE funds, private equity is a form of professional

investing that involves acquiring an ownership stake in a company and keeping it private—as opposed to trading on public stock markets. PE and VC are generally medium or long-term investments in which fund managers actively participate in the company's operations over a relatively extended period. Fund managers raise investment capital from various sources, including institutional investors such as pension funds, insurance groups, sovereign wealth funds, as well as private investors. When the time comes to realize returns and exit investments, the fund managers sell their stakes in portfolio companies and return the invested funds to their investors. Venture capital as equity provided for a limited time by external investors to small and medium-sized enterprises with an innovative product, production method, or service that has not yet been validated by the market, thus posing a high investment failure risk. However, if market success is achieved, it offers significant capital appreciation.

Generally, fund management can be divided into three phases: capital acquisition, investment, and divestment. The goal of this article is to analyze the performance of portfolio companies in terms of return on equity, which achieved sufficiently high economic results to allow for an initial public offering on the Warsaw Stock Exchange. The introductory part outlines shortly the objectives and motivation for writing the paper. The introduction should provide a theoretical context for the discussion in the body of the paper and point explicitly the purpose of the article.

Divestment refers to the actions taken by an investor to exit an investment, meaning the sale of equity stakes in a portfolio company—either on the private or public market—to one or more entities. Divestment marks the final stage of cooperation between a company and the investment fund. Investors finance fast-growing enterprises with the intention of selling their stakes after a few years. When a fund exits one company, it often quickly reinvests in another. Many funds admit that they consider the divestment strategy even before signing the investment agreement and start preparing the company for it from the first day of financial involvement. Typically, the investor plans to exit at the end of the company's dynamic growth phase. The fund's participation in managing the portfolio company and its involvement in developing or modifying the company's strategy is aimed at ensuring planned development and achieving performance levels that make a timely divestment possible. The most common methods used by venture capital and private equity funds to exit an investment include:

1. Initial Public Offering.
2. Sale of shares to a strategic investor – trade sale.
3. Sale of shares to remaining company owners – buyback.
4. Sale of shares to another fund or financial investor.
5. Management buyout by the company's own managers.
6. Buyout by external managers.
7. Management-employee buyout by both company managers and regular employees.
8. Company acquisition by another investor in exchange for the investor's shares.
9. Company liquidation and redemption of shares.

An IPO is not solely a method of exiting an investment, but rather the first stage of divestment. The actual exit occurs through the sale of shares on the stock exchange. This is considered the most desirable and model form of divestment for companies financed by funds. Across all markets where venture capital funds operate, going public is often the preferred exit route, enabling the sale of shares on the exchange. However, this process is time-consuming and relatively expensive, meaning that the portfolio company often requires extensive support from the fund to complete it successfully.

For a well-performing company, the benefits of going public can far outweigh the costs of preparing for the listing. An IPO can lead to significant profits, but it is a path reserved for large companies with high profitability, transparent organizational structures, and clearly defined financial flows. Key factors influencing the IPO process include the competence of the management team, the quality of corporate governance, and the shareholder structure. The risk associated with exiting via an IPO is particularly significant during a market downturn. A fund is not always able to sell all of its shares immediately after the company goes public, as this is regulated by existing laws. The decision to exit via IPO heavily depends on stock market conditions. In times of economic prosperity, such transactions can be highly profitable, while during downturns, they may end in failure. Performance itself of portfolio companies can also influence IPOs transactions. This study is one of the first at the Polish market and the first one that take into the study such a long period of time (2013-2023).

2. Literature review

Academic literature reveals that venture capital funded companies show superior and much advanced performance to regular companies that does not have venture capital support. Those firms contribute in many ways to the development of economies through boost of the turnovers, innovations, the creation of jobs as well as an exceptional growth rate. Their high level of investments and returns also influences many different areas of the economy. However in general, in the macro economy the proportion of companies that receive venture capital funding is limited and very small. Despite that, there has been a rapid growth in the availability of VC/PE funds over the years in the different branches and economies. One can observe that there is still lack of this kind of investors in many sectors. Researchers conclusions have indicated that significant variance in performance between companies that are supported by VC/PE and regular firms can be attributed to the VC/PE investors. This outcome should then led us to the important question - what capabilities of VC/PEs contribute to the performance variation of the supported companies. There has been high number of research evidence to indicate that managerial and value addition capabilities of venture capital dominate the selection capabilities in explaining the performance variation. The relationship between entrepreneur and

investor is a broad area for VC/PE value added research. Most important might be acceptance of the investment manager (in most cases its and current owner of the company) through the management of the venture. Cable and Shane conclude that a cooperative relationship between entrepreneur and investor is even more important for the positive development of a company than a provision of money itself. This relation is characterized by as a socially complex inter-organizational relationship. They argue that the relationship between two parties increases in its social complexity and therefore becomes more and more difficult to imitate (Cable et al., 1997). This in turn led to an improvement in the company's performance. At the certain period in the investment time span venture capital funds should conduct an effective divestment process. IPO as desirable exit for the funds is the outcome of that process. When a venture capital or private equity sponsor conducts an IPO of a portfolio firm, it not often sells significant stake of its investment, usually remaining a large block holder in the newly listed firm for a longer and much extended period. This practice is consistent with the recognition that retention of shares in an IPO is a signalling device that mitigates adverse selection intrinsic to equity issuance (Leland, Pyle, 1977). There were clearly benefits of a healthy IPO market. Research suggests that IPOs finance growth and stimulate innovation, productivity and job creation. After an IPO, venture capital funds generally block and hold its governance rights, maintains board representation, monitor managers, influences corporate decisions and sometimes is bound by regulations that restrict its share trading. Because a sponsor influences a firm's operations until its ownership is sold (typically some years after an IPO), venture capitalist is the type of block holder that researchers (Demsetz, 1986) viewed as an effective corporate monitor. At the same time, the limited horizon intrinsic to VC/PE's business model, creates pressure for sponsor divestment after an IPO, including the fact that a sponsor's limited partners pay high fees for managing. Venture capital and private equity contracts govern long-term relations between entrepreneurs and their investors in a way that establishes path for capital gain growth, cash flow, control rights and exit horizon. The long-term nature of VC/PE–entrepreneur relationships leave entrepreneurs open to exploitation by VC/PE funds (Fried, Ganor, 2006; Atanasov et al., 2006), and VC/PE funds open to expropriation by entrepreneurs (Gompers, 1998; Casamatta, 2003; Schmidt, 2003; Kaplan, Strömberg, 2003). It is therefore natural for relation and its contracts to depend on the bargaining power of the VC/PE funds and the entrepreneurs. Further, as high-tech start-up entrepreneurial firms do not have sufficient cash flows to pay interest on debt or dividends on equity, contracts are established in a way that control rights are allocated over divestment decisions (Sahlman, 1990; Black, Gilson, 1998; for related theoretical work, see Aghion, Bolton, 1992; Berglöf, 1994; Trester, 1998; Garmaise, 2000; Bascha, Walz, 2001; Schwienbacher, 2007; Neus, Walz, 2005). A successful divestment may involve an IPO, or an merger or acquisition (often referred to as a “trade sale”). There is limited number of research that covers ROE analysis for VC backed IPOs. However there are some studies that show that PE/VC backed IPOs companies have a lower leverage ratio in the first 5 years after the IPO, in comparison with those not financed by PE/VC. These companies,

in addition to having more capital options, must return to the PE/VC funds the investments made by them. (Carvalho et al., 2013) show that 25% of the exit from investment of PE/VC funds between 2004 and 2009 were through IPO. In this sense, companies invested by PE/VC are more likely to issue shares instead of debt. Further studies also found evidence that companies financed by PE/VC have a higher level of profitability - as measured by ROE - in the short term, i.e., in the first three years after the IPO. In the same direction, companies financed by PE/VC show a higher level of sales growth in the first 3 years after the IPO. With regard to the ROE variable, (Morsfield, Tan, 2006) argue that companies invested by PE/VC funds tend to have on average, better performance in their investments when compared to those not invested by PE/VC. Caselli (Caselli, 2009) analyzed 804 investments made by 87 channels of Investments of 58 PE/VC Management Organizations in Italy in the period of 1999-2005 and divested not before 2007. The author also concluded that the high IRR return is driven by sales growth, return on assets (ROA) and return on equity (ROE). In terms of profitability, the results indicated that these companies perform better, as measured by ROA, in the first 3 years after the IPO. These companies also presented a superior result when considering sales growth as a variable of operational performance. Analyzing Polish data from the 2013–2023 period it shows some picture of divestment market situation. IPOs account for 13.7% of number and 13.16% of value of all divestments of VC/PE portfolio companies.

Table 1.

Number and Value of VC/PE Fund Divestments in the Polish Market (2000-2023)

Divestment	Number of divestments 2013-2023	Share in %	Value 2013-2023	Share in %
Sale to trade buyers	146	35,10%	2 236,03	43,95%
Divestment by public offering	57	13,70%	669,40633	13,16%
Write off	12	2,88%	189	3,71%
Repayment of preference shares/ loans or mezzanine	27	6,49%	122	2,40%
Sale to another private equity firm	42	10,10%	938	18,43%
Sale to financial institutions	36	8,65%	640	12,58%
Management/Owner buy-back	73	17,55%	256	5,04%
Divestment by other means	23	5,53%	37	0,73%
Total	416	100,00%	5 088,05	100,00%

Source: Own calculations based on EVCA data.

The most common method of exiting investments in the period 2013-2023 was the sale of shares by funds to strategic investors, accounting for over 35% of all transactions. Initial Public Offerings (IPOs), totalling 57 transactions, represented nearly 13.7% of all exits, and 13.6% in terms of value. This indicates a significant share within the overall structure of divestment transactions. The number of divestments through IPOs on the Warsaw Stock Exchange are illustrated in Figure 1.

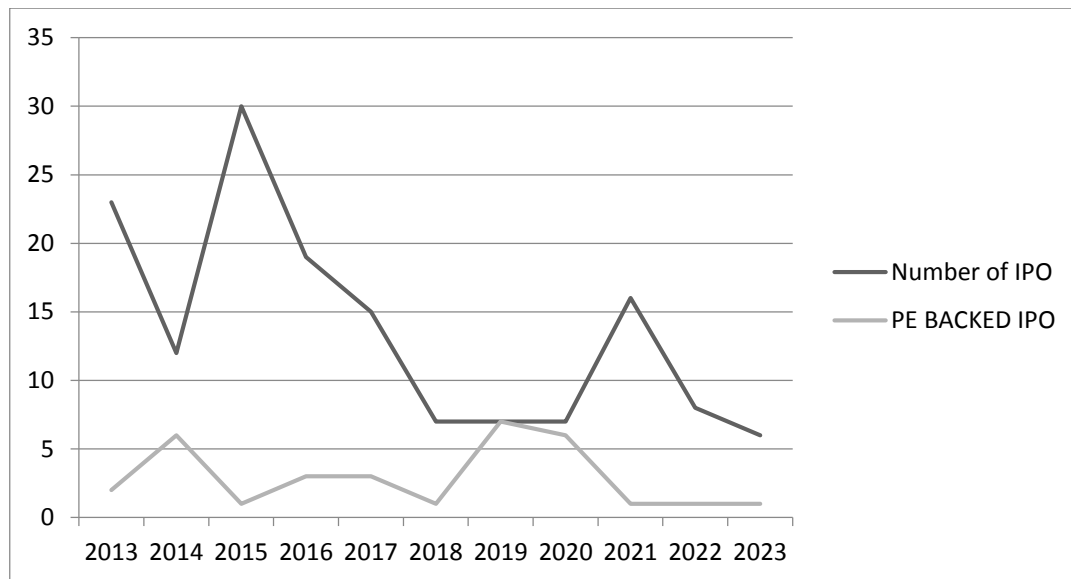


Figure 1. Number of IPO transactions on the Polish market carried out by PE/VC funds in the period 2013-2023.

Source: Own calculations based on EVCA and InvestEurope data.

When analyzing IPO transaction data on the Warsaw Stock Exchange carried out by companies backed by VC or PE capital, it can be concluded that they account for approximately 10% of the total value and number of all transactions. This is a relatively high share, providing grounds to assert that VC and PE funds are active participants in the capital market.

3. Methods

There are many classic and specific indicators that can be used to measure the return rates on VC and PE-type investments. Common financial metrics such as the Internal Rate of Return (IRR) and the Time-Weighted Rate of Return (TWR) yield different results when applied to VC investments and may not fully capture the effectiveness of fund managers. Various forms of internal rate of return can be found in the literature. In the context of venture capital and private equity investments, IRR can be calculated at multiple levels.

The basic classification used by EVCA includes:

- Gross IRR on realized investments.
- Gross IRR on all investments.
- Net IRR for investors.

Another approach to evaluating funds and comparing them with the returns of public market companies is the Public Market Equivalent (PME or index method). This is a return metric based on a market index, adjusted to reflect the irregular cash flows typical of VC funds. It is related to a money-weighted return (similar to IRR) in such a way that the PME rate is the

return an investor would achieve by investing in a public index during the periods when the VC fund calls capital, and selling the index when the fund distributes proceeds. This strategy is designed to replicate the irregular investment and divestment patterns of a venture capital fund as closely as possible in order to compare the achieved returns more accurately. The indicator answers a simple question: how much (in net present value terms) would an investor need to invest in a public market index to generate one monetary unit of return equivalent to that received from a VC or PE fund investment. This measure allows for a direct comparison of returns from public market investments and those from VC or PE funds. In this way, we can obtain a comprehensive comparison of investment performance against an appropriate benchmark.

Mathematically, the model is represented as follows:

$$PME = \frac{\sum_{t=1}^T cf_t \prod_{i=t+1}^T (1 + R_{Ii})}{\prod_{t=1}^T (1 + R_{It})}$$

where:

R_{It} – net return from the public market index over the period t ,

cf_t – normalized positive cash flow of the VC fund over the period t .

As can be observed, public index return rates are gross returns that include management fees. An alternative definition of the PME indicator model, presented by S. Kaplan and Scholar, states that the PME ratio is the quotient of the discounted fund distributions from realized investments to the discounted fund inflows (investor contributions), where the discounting is based on the return rate of the chosen benchmark investment. Mathematically, the formula is as follows:

$$PME_i = \frac{\sum_{t=1}^T (CFO_{ti} \prod_{n=0}^t (1 + r_{Bn})^{-1})}{\sum_{t=1}^T (CFI_{ti} \prod_{n=0}^t (1 + r_{Bn})^{-1})}$$

where:

CFO_{ti} – fund distributions from investment i in period t .

CFI_{ti} – fund inflows for investment i in period t .

r_{Bn} – total return rate of the benchmark index B in period t .

If the PME ratio exceeds 1, it indicates that investments in VC or PE funds outperform the benchmark and provide higher returns than the public market. Conversely, if the PME is below 1, then public market investments are more effective than VC and PE investments. From the investor's perspective, it is important to determine whether investing in venture capital funds offers higher efficiency compared to public market investments.

Apart from IRR, other indicators are also used to measure fund performance. Multiples used by NVCA and EVCA include:

- DPI (Distributions to Paid-In Capital): the ratio of profits distributed to fund participants (net of fees) over a given period, relative to committed capital.
- RVPI (Residual Value to Paid-In Capital): the ratio of the residual value of the fund (the remaining capital held by the fund, net of fees and interest) to the committed capital.
- TVPI (Total Value to Paid-In Capital): the sum of DPI and RVPI, representing the total value generated relative to committed capital, net of costs and interest.

An additional indicator is PIC (Paid-In Capital to Committed Capital), which shows the portion of committed capital that has been actually paid into the fund by investors.

When assessing the performance of individual companies, various capital market indicators can be compared. During investments in enterprises, funds often rely on valuation multiples based on the assumption that the market reflects the company's value most accurately. In the case of young companies, however, the full set of valuation multiples may not be applicable. The most commonly used multiples are based on earnings categories.

Frequently applied valuation multiples include:

- Revenue multiples (P/Sales).
- Operational multiples (e.g., number of customers, area, number of operations).
- Book value multiples (P/Book Value).
- Earnings multiples (EBITDA, EBIT, gross profit, net profit).

Other important indicators include profitability ratios such as return on equity (ROE), return on assets (ROA), and return on sales (ROS)—which are part of the financial analysis applied to all types of companies, both private and public. Analysis was conducted of the ROE of companies that carried out IPO transactions on the Warsaw Stock Exchange and were also backed by venture capital or private equity funding. ROE was selected for this analysis as it is the most critical metric for equity holders and occupies a prominent position among financial indicators, for example, at the top of the DuPont Analysis model.

Empirical research on the effects of divestment processes carried out by private equity and venture capital funds is conducted at various levels and presents diversified results, especially when different exit strategies of the funds are considered. For companies in which a fund executed an IPO transaction, three primary areas of research can be identified:

- Underpricing of the returns on shares offered in IPOs by private equity or venture capital funds.
- Costs of the IPO process for the analyzed companies.
- Return on equity of the portfolio companies owned by private equity or venture capital funds.

These issues are considered key for assessing the effectiveness of investments in portfolio companies and may distinguish such firms from other companies conducting IPOs without the support of high-risk capital funds. The capital and stock markets allow for a comprehensive evaluation of companies in terms of valuation, divestment costs, and return on equity performance compared to other companies going public. During an IPO, the fund partially disposes of its shares in the portfolio company and eventually exits the company entirely. Funds are generally not interested in remaining shareholders of companies whose stock value has stabilized and no longer delivers above-average returns. This provides an opportunity to study the performance of portfolio companies after the fund exits their shareholder structure at the point when they lose financial, personnel, and managerial capital support. This represents a kind of "test" for the companies and is a situation that significantly affects their ability to maintain operational efficiency and stabilize their share price on the stock exchange after the fund's withdrawal. The exit of the fund means the company begins to operate independently, without the support typically provided by venture capital or private equity funds. This introduces new conditions for the company, which should already be mature enough to continue generating positive financial results, especially as a publicly listed firm. Studies conducted on portfolio companies of foreign funds and the effects of fund divestments indicate that after IPOs are completed, a deterioration in the financial condition of portfolio companies is often observed specifically, those whose shares have been floated publicly.

To assess the scale and durability of changes in the financial condition of portfolio companies of venture capital and private equity funds, the **return on equity** indicator was used. In the context of evaluating efficiency and enterprise value, ROE is a key variable in the formulation, implementation, and monitoring of financial strategies aimed at providing shareholders with capital gains, dividends, and increased market value. ROE is considered the most important measure of economic performance of a business and its management tools, as changes in ROE reflect the enterprise's activity in both financial and non-financial spheres such as marketing. Empirical studies conducted to verify the research hypothesis—namely that venture capital and private equity portfolio companies experience a temporary decline in financial performance following their stock market debut—confirm this effect. In particular, a decline in ROE was observed for almost entire companies, whose IPOs on the Warsaw Stock Exchange took place between 2013 and 2023. This research period was chosen to allow for a comprehensive review of VC- and PE-backed companies that carried out IPOs on the WSE, and to include the longest possible timeframe to track their medium- and long-term performance post-IPO. During the indicated period, 46 companies debuted on the WSE, with venture capital and private equity funds listed as shareholders immediately prior to their IPOs.

To verify the research hypothesis, the traditional formula for calculating ROE was applied, where the net income generated by the company in a given period is related to the arithmetic average of the book value of shareholders' equity. ROE serves as a synthetic measure of how effectively a company utilizes its owners' assets and resources. Its value and changes depend

on many factors and operational conditions of the enterprise. For the purpose of causal analysis, **pyramidal decomposition** was used, breaking ROE down into three components and presenting it as follows:

$$ROE_n = \frac{EAT_n}{\bar{E}_n} = ROS_n \times AU_n \times EM_n.$$

$$ROE_n = \frac{EAT_n}{S_n} \times \frac{S_n}{\bar{TA}_n} \times \frac{\bar{TA}_n}{\bar{E}_n}.$$

where:

ROE_n – return on equity (ROE) in year n,

EAT_n – net income in the financial year n,

EM_n – equity multiplier in year n,

ROS_n – return on sales om year n,

AU_n – asset productivity ratio in year n,

S_n – sales revenue in year n,

$\bar{E}_n$ – average equity in year n,

$\bar{TA}_n$ – average total assets in year n.

To numerically determine the impact of changes in the net profit margin, equity multiplier, and asset productivity ratio on variations in the return on equity (ROE), the method of successive substitutions will be applied. The use of this method requires adherence to the following research discipline:

- Determining the **total deviation** between the value of the return on equity achieved in a given year and its value in the preceding year, i.e.:

$$O_{ROE_n} = ROE_n - ROE_{n-1},$$

where:

O_{ROE_n} – total deviation of the return on equity coefficient in year n,

ROE_{n-1} – return on equity in the previous year, serving as the reference base,

other notations as above.

- Identification of factors influencing the total deviation and the causal relationship between these variables:

$$f(ROE_n) = ROS_n \times AU_n \times EM_n,$$

- Performing subsequent substitutions with respect to individual factors and determining the magnitude of the corresponding deviations:

$$O_{ROE_n} = O_{ROS_n} + O_{AU_n} + O_{EM_n},$$

$$O_{ROS_n} = ROS_n + AU_{n-1} \times EM_{n-1} - ROS_{n-1} \times AU_{n-1} \times EM_{n-1} =$$

$$(ROS_n - ROS_{n-1}) \times AU_{n-1} \times EM_{n-1},$$

$$O_{AU_n} = ROS_n + AU_n \times EM_{n-1} - ROS_n \times AU_{n-1} \times EM_{n-1} = (AU_n - AU_{n-1}) \times ROS_n \times EM_{n-1},$$

$$O_{EM_n} = ROS_n + AU_n \times EM_n - ROS_n \times AU_n \times EM_{n-1} = (EM_n - EM_{n-1}) \times ROS_n \times AU_n,$$

where:

O_{ROS_n} – partial deviation resulting from changes in the sales profitability ratio,

O_{AU_n} – partial deviations resulting from changes in the asset productivity ratio,

O_{EM_n} – partial deviation resulting from changes in the equity multiplier,

Other notations remain as previously defined. A summary of partial deviations was compiled, and conclusions were drawn based on a deterministic approach. The data were collected using the prospectuses of companies undergoing the IPO process and from financial statements prepared after the IPO transaction.

Research Strengths

- Methodological clarity - The study applies a well-established DuPont decomposition (pyramidal model of ROE), which is a standard and theoretically grounded approach for analyzing the determinants of return on equity.
- Deterministic framework - The method of successive substitutions allows for precise, numerical determination of the impact of individual factors (profitability, asset efficiency, leverage) on ROE. This makes causal inference more transparent than simple correlation analysis.
- Data reliability - using IPO prospectuses and post-IPO financial statements ensures that the data come from verified and publicly available sources, which enhances transparency and replicability.

Limitations and Weaknesses

- Methodological Limitations - lack of statistical validation, the deterministic method assumes linear and proportional relationships between the components of ROE. It does not test statistical significance, multicollinearity, or non-linear effects. Therefore, causal inferences may be mechanical rather than empirical.
- Static framework - the pyramidal decomposition provides a snapshot rather than capturing dynamic interactions over time. It does not model feedback effects or lagged relationships between profitability, asset use, and leverage.
- No control for external variables - factors such as market conditions, industry differences, macroeconomic trends, or firm-specific risks are not incorporated. This omission limits the explanatory power of the model.

Data-Related Weaknesses

- Small and selective sample - focusing solely on companies during and after the IPO process restricts the generalizability of findings. IPO firms are typically in a transitional phase (e.g., restructuring capital, rapid growth), making them non-representative of mature firms.
- Potential inconsistencies in reporting standards - prospectuses and post-IPO reports may differ in accounting methods or assumptions (e.g., fair value adjustments, goodwill recognition), which could distort comparability of financial data.
- Short observation window - If the analysis covers only a few years post-IPO, it fails to capture long-term profitability trends and structural changes in performance.

Conceptual Weaknesses

- Overreliance on accounting measures - ROE and its components are accounting-based, and thus susceptible to earnings management, valuation choices, and timing effects. They may not accurately reflect economic performance or shareholder value creation.
- Simplified causal structure - The decomposition assumes a unidirectional influence from profitability, assets, and leverage to ROE. In reality, these relationships are interdependent and may involve reverse causality (e.g., higher ROE enabling higher leverage).

4. Results

The analysis of changes in this indicator covered a period of two years prior to the IPO debut on the Warsaw Stock Exchange, the year of the initial listing (n_0), and three subsequent years following the IPO. During the course of the analysis, periods were excluded in which calculating the coefficient based on the adopted research methodology and the availability of empirical data was not feasible. In cases where negative equity was reported during selected periods, the ROE was not calculated. When analyzing the return on equity of portfolio companies backed by investment funds, it should be noted that most of the examined companies generated positive financial results during the analyzed period.

Table 2.
Number and share of VC/PE backed IPO

		Analyzed period					
		n_{-2}	n_{-1}	n_0	n_{+1}	n_{+2}	n_{+3}
Profitable companies	number	36	44	40	34	34	30
	share [%]	94,74	95,65	86,96	73,91	77,27	73,43
Deficit companies	number	2	2	6	12	10	12
	share [%]	5,26	4,35	13,04	26,09	22,73	26,57

Source: Own calculations.

Analyzing the data presented in Table 2, it should be noted that in the years preceding the IPO on the Warsaw Stock Exchange, only two companies reported operating losses. In the year of the IPO, this number increased to six companies, and in the following periods, the number of loss-making companies rose to twelve. With this data, it is also possible to examine the average ROE values achieved by the analyzed companies. In the two years prior to the initial public offering of shares issued by portfolio companies of private equity and venture capital funds, the average return on equity amounted to 25.32%. In the year directly preceding the IPO transaction, the ROE increased slightly to 26.18%. However, in the year of the IPO, it dropped significantly to 15.23%, and in the following years after the debut, the average ROE declined further to 7.29%, 7.98%, and 3.05%, respectively. This indicates that VC and PE backed companies follow a similar pattern to other firms conducting IPOs: in the pre-IPO period, they report very strong return on equity results, which then systematically deteriorate in the years following the IPO. Notably, only two companies showed an increase in ROE between year n_{-1} and year n_{+1} .

Table 3.
Results of the ROE changes in VC/PE backed IPO

Specification	Analyzed period					
Arithmetic mean	n_{-2} ,32	n_{-1} ,18	n_0 5,23	n_{+1} ,29	n_{+2} ,98	n_{+3} ,05
Median	19,56	21,62	14,51	5,56	7,23	4,05
Standard deviation	23,41	20,49	12,61	10,18	11,89	26,21
Lower quartile	11,62	14,73	7,28	0,01	0,34	3,31
Upper quartile	37,88	38,05	24,29	14,28	17,43	16,59
Interquartile range	26,26	23,32	17,01	14,27	17,09	13,28
Minimum	-10,39	-16,51	-11,73	-7,51	-18,78	-72,21
Maximum	92,55	72,94	36,55	33,21	23,98	27,01
Number of companies	36	40	46	46	42	42

Source: Own calculations.

To confirm the statistical significance of the results regarding the behavior of the return on equity before and after the IPO process, a paired sample Student's t-test was conducted. For this purpose, a comparison was made between the ROE values obtained in the period between year n_{-1} and year n_{+1} .

Assuming a normal distribution of the variables under study, the following null hypothesis (H_0) was formulated: there is no difference between the means, i.e., the means are equal:

$$H_0 : u_{n-1} = u_{n+1}$$

In contrast, the alternative hypothesis H_1 stated that:

$$H_1 : u_{n-1} > u_{n+1}$$

The results of the study indicate that there are grounds to reject the null hypothesis in favor of the alternative hypothesis.

Table 4.

Results of the Paired Sample Student's t-Test for mean ROE values

Specification	ROE_{n-1}	ROE_{n+1}
Mean	0,2653	0,0721
Variance	0,0419	0,0105
Observations	42	42
tStat	4,6528	
P(T<=t) one sided	0,0001	
one sided T Test	1,7192	
P(T<+=t) two-tiled	0,0001	
Two-tiled T Test	2,0539	

Source: Own calculations.

Analyzing the results presented in table 4. it can be concluded that the differences in the return on equity levels within the examined group of companies are statistically significant. The ROE levels in the analyzed firms are higher before their introduction to the public market compared to the period following their stock market debut. It should be noted that numerous diverse factors influence the ROE, such as asset utilization efficiency, asset structure, and profit margins. Analyzing these individual components that affect ROE is the next stage of the research, which will complement the assessment of the effectiveness of companies that conduct IPO transactions on the Warsaw Stock Exchange. The subsequent stage of the study should include a comparison with companies that have conducted IPOs without the support of VC or PE funds.

5. Discussions

It can be concluded that the differences in the return on equity (ROE) levels within the examined group of companies are statistically significant. The ROE levels in the analyzed firms are higher before their introduction to the public market compared to the period following their stock market debut. It should be noted that numerous diverse factors influence the ROE, such as asset utilization efficiency, asset structure, and profit margins. Analyzing these individual components that affect ROE is the next stage of the research, which will complement the assessment of the effectiveness of companies that conduct IPO transactions on the Warsaw

Stock Exchange. The subsequent stage of the study should include a comparison with companies that have conducted IPOs without the support of VC or PE funds.

6. Conclusions

Venture capital and private equity investments are important part of financial markets across the globe. Economies with high stake of those investments are among leading ones. Crucial factor for the activity of those funds is well working stock market and possibility of IPO transactions. In this paper only performance in terms of return on capital was examined, and it gave the outcome that this indicator vary before the IPO and afterwards. It show statistical significance. Very similar situations happen among non VC backed IPOs. Future research can examine further indicators such as return on assets and return on sales, costs of IPO and underpricing. It can also can possibly explain the comparison of performance of CEE region IPOs or European IPOs in general, and European VC-backed IPOs in particular, with their counterparts. Central Eastern European countries and other European markets possess a set of distinct characteristics, including culture, institutional factors, legal environments, political systems, and corporate governance regimes. In addition, important divergence in two corporate governance models, Continental European version Anglo Saxon, may lead to differences in the VC participation as well as VC-back IPOs' performance. These factors can explain divergence in performance of VC-backed IPOs in different regions, and worth future research efforts.

The research provides a systematic and quantitative assessment of ROE, breaking it down into profitability, asset efficiency, and leverage components. This decomposition allows stakeholders—investors, analysts, and managers—to pinpoint the key drivers of financial performance rather than relying on aggregate indicators alone. By analyzing data from IPO prospectuses and post-IPO financial statements, the study offers insights into how newly public firms manage equity and generate returns. This is crucial for investors and underwriters seeking to assess post-IPO performance risk and make informed investment decisions.

The research is important because it moves beyond aggregate measures of profitability to reveal the underlying drivers of ROE, particularly for IPO firms. Its impact spans investment analysis, corporate strategy, academic research, and regulatory oversight, and the information obtained can serve as a foundation for predictive modeling, benchmarking, and further sectoral or cross-country studies.

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ASSESSING OPEN DATA MATURITY ACROSS EUROPE: EVIDENCE FROM A CLUSTER ANALYSIS

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Purpose: The aim of this article is to determine the state of open data maturity in European countries. Two research questions were addressed: RQ1: What are the distributions of the main dimensions describing open data maturity in European countries? RQ2: What is the stratification of European countries in terms of open data maturity?

Design/methodology/approach: To achieve the aim of the article, an analysis of the open data maturity dimensions for 34 European countries was carried out based on data from 2024. The distributions of these dimensions were analyzed, and a cluster analysis was performed on the collective open data maturity indicators and for each dimension individually.

Findings: The results indicate that open data maturity among European countries is high, and these countries can be divided into two clusters. The cluster of countries with high open data maturity is more numerous.

Research limitations/implications: Due to the small number of observations, cluster analyses were conducted on a limited number of grouping variables. The study covered only European countries. Future research could include studies comparing the open data maturity of European countries with other countries.

Practical implications: Our research has revealed which European countries are leading the way in open data maturity. Observing the solutions implemented in these countries can help other countries improve their open data maturity.

Social implications: Because comparing open data enables countries to learn from each other, the societal implications of our research are related to strengthening the European data community. This builds cohesion among EU member states in terms of openness, interoperability, and digital transformation.

Originality/value: The novelty of our research is that we present clusters of European countries not only in terms of overall open data maturity, but also in terms of individual dimension indicators. This provides broader insight into which European countries are leaders in open data maturity and identifies them as countries worth emulating.

Keywords: open data, open data maturity, cluster analysis.

Category of the paper: Research paper.

1. Introduction

Public sector open data is data collected by public bodies that is made available free of charge for reuse for any purpose (Lnenicka et al., 2024; Cunha et al., 2024). Public sector data is therefore shared on a non-personal and non-commercial basis. This way, citizens' rights to protect personal data are not violated, nor are commercial entities' trade secrets violated. Open data becomes a source of innovation, not only digital but also environmentally friendly. It is a raw material for businesses and startups, enabling the creation of new data-driven services, applications, and products (Mohamad, 2025). Additionally, opening public data strengthens the transparency and accountability of institutions towards citizens, which contributes to building social trust.

Open data maturity reports indicate that development across the four dimensions of open data maturity (Policy, Portal, Impact, and Quality) is uneven. For example, in the 2019 report, the Impact dimension was the weakest among EU countries (Blank, 2020). In the 2023 report, the average maturity increased, and the increase in Impact and Quality was the most significant (Page et al., 2023). This suggests that while countries are making progress overall, there are still significant differences in the pace of development across dimensions. Therefore, although open data maturity reports present aggregated data, the literature lacks in-depth analysis based on statistical modeling that describes how countries differ not only in their overall maturity but also in their profiles across dimensions. Therefore, there is an urgent need to fill this research gap. Therefore, this paper addresses two research questions:

RQ1: What are the distributions of the main dimensions describing open data maturity in European countries?

RQ2: What is the stratification of European countries in terms of open data maturity?

The authors of this article aimed to answer the research questions posed. This goal was achieved through a literature review and analysis of variables measuring open data maturity in 2024 in European countries. The analysis was conducted by examining the distributions of variables describing the dimensions and performing cluster analysis on each of the open data maturity dimensions.

The novelty of our research is that we present clusters of European countries not only in terms of overall open data maturity, but also in terms of individual dimension indicators. This provides broader insight into which European countries are leaders in open data maturity and identifies them as countries worth emulating.

The structure of the article is guided by the stated goal. First, a literature review is presented, focusing on the potential of open data in digital and green transformations and presenting the dimensions of open data maturity. This is followed by a presentation of the analytical methodology, followed by the analytical results, and finally, a discussion of the obtained results.

2. Literature background

2.1. The potential of open data

In the digital era, open public data (ODG) has become a key element in the transformation of governance towards data-driven models. In this way, they represent an important initiative for the development of the digital economy. An analysis of the literature on public open data revealed that public data is disclosed to unlock its intrinsic value and foster innovation and digital transformation (Lan et al., 2025; Sun et al., 2025; Wang, Zhou, et al., 2025; Chen, Zhang, 2024). It was found that OGD has a positive impact on the innovativeness of enterprises, and this is achieved mainly by reducing information asymmetry of enterprises, increasing the scale of acquiring enterprise resources and improving the operational efficiency of enterprises (Sun et al., 2025). The use of open data is currently a rapidly growing area of research in academia, and businesses are the main actors encouraged to use public data to generate value (Chen, Zhang, 2024). This is due to the fact that the digital transformation of enterprises is necessary to obtain new strategic advantages in the future and support high-quality development.

Public data exhibits the characteristics of public goods. This means that many businesses can access public data resources without increasing costs, or even for free. In this way, public data provides businesses with a competitive advantage in terms of cost. Moreover, public data has strong integration capabilities and can be incorporated into management, production, and sales processes in various ways. This enables data integration and the digitization of products, services, and processes. This is how digital transformation and organizational change are fueled, stimulating the development of new products, processes, and technologies (Chen, Zhang, 2024). Additionally, open data supports the green transformation by enhancing environmental performance (Zhou, Huan, 2024; Ling et al., 2025; Luo et al., 2025; Xing et al., 2024; Xu, Mu, 2025; Wu, Xie, 2024; Wu, 2024; Wang, Chen et al., 2025; Peng, Xiao, 2024). For example, open meteorological, hydrological, geographic, and energy data allow companies to optimize energy consumption, plan logistics, and manage environmental risks. Furthermore, publicly available emissions data helps companies monitor their own environmental indicators and benchmark themselves against the industry. Open data enables the creation of new products, applications, and business models that help reduce environmental impact. Examples include smart grid systems, carbon footprint tracking tools, and circular economy platforms. When businesses and public institutions share data (e.g., on waste, energy, logistics), data ecosystems are created that support the circular economy. This facilitates, among other things, recycling, the exchange of secondary raw materials, and the planning of low-emission supply chains (Dwivedi et al., 2023). This confirms that green innovations are one of the most important paths to reducing the impact of climate change and achieving global environmental sustainability (Guo et al., 2025).

2.2. Open data maturity

Open Data Maturity (ODM) is an annual assessment of European countries regarding the extent to which public sector data is open, the extent to which its reusability is supported, and the structures and mechanisms in place for this process. Data is collected via a survey. Participation in ODM is voluntary. It covers the EU-27, EFTA countries, EU candidate countries, and other European countries.

Open Data Maturity is a framework for assessing countries' progress in implementing and managing open data policies (EU, 2024a). It encompasses four key dimensions: Policy, Portal, Quality, and Impact. Together, they provide a comprehensive picture of the development and effectiveness of national open data ecosystems. Each dimension has its own indicators, which serve as survey questions, allowing a country to receive points.

The Policy dimension refers to the strategic and institutional framework supporting the implementation of open data initiatives. It encompasses the existence of national legal frameworks or open data strategies, as well as mechanisms for governance and coordination between different levels of government: national, regional, and local. Furthermore, the degree of policy implementation is analyzed, including data publication plans, monitoring mechanisms, and actions promoting and supporting data reuse. This dimension is measured by indicators such as the policy framework, governance of open data, and open data implementation (EU, 2024a). A mature policy in this area means that open data is an integral part of the country's broader digital strategy, and its implementation is systematic and long-term.

The Portal dimension addresses the features and functionality of national open data portals. The assessment assesses the availability of user-centric features and advanced tools, such as search engines, opinion and feedback mechanisms, and discussion forums. The availability of usage statistics, the portal's durability and stability, and the thematic and administrative scope of published data are also considered. This dimension is measured by indicators such as: portal features, portal usage, data provision, and portal sustainability (EU, 2024a). A well-developed data portal provides a central point of access to public sector information, supporting transparency in government activities and user engagement.

The Quality dimension refers to the completeness, accuracy, and timeliness of published data and metadata. Metadata compliance with international standards, such as DCAT-AP, as well as the degree of automation of metadata acquisition and integration processes from various sources, are assessed. High data quality is crucial for effective reuse, ensuring interoperability, and building trust among users. This dimension is measured by metrics such as: metadata currency and completeness; monitoring and measures; DCAT-AP compliance; and deployment quality and linked data (EU, 2024a). The dimension therefore reflects the technical and organizational maturity of open data management processes in each country.

The Impact dimension focuses on measurable outcomes and benefits resulting from open data reuse. It includes assessing strategic awareness and the existence of mechanisms to monitor, promote, and support data reuse. It also examines evidence of specific cases of use and their tangible impacts. This dimension encompasses various types of impact, including economic, social, environmental, and political. It demonstrates the contribution of open data to innovation, public policymaking, and societal development. Measuring impact, however, is one of the greatest challenges in assessing open data maturity, as it requires both qualitative and quantitative evidence of actual effects. This dimension is measured by indicators such as: strategic awareness; measuring reuse; and created impact (EU, 2024a).

In recent years, many countries have made significant progress in disclosing public data (Sołtysik-Piorunkiewicz, Zdonek, 2021; Zdonek, Sołtysik-Piorunkiewicz, 2021; Zdonek, 2021; Luo et al., 2025; EU, 2024a). However, differences persist in the diversity and quality of data shared by these countries. These differences should be monitored and addressed. According to what we could find, there are no studies addressing and reporting on differences between European countries in specific dimensions of open data maturity. That's why we decided to conduct our own research to fill this research gap.

3. Methods

Data on open data maturity in individual European countries is for 2024. It was taken from the official European Union website dedicated to open data (EU, 2024b). This data is collected annually to measure European countries' progress in promoting and facilitating the accessibility and reuse of public sector information. The data is collected through a survey that measures open data maturity across four dimensions, each measured by separate indicators. This method collected data for 34 countries, measuring 23 variables. The data included variables related to the dimensions of open data maturity and indicators describing these dimensions. The data also included the overall open data maturity for each country. This variable was called Composite Maturity and was calculated from four main dimensions.

To answer the first research question, we examined the distributions of the four dimensions of open data maturity and the overall maturity variable Composite Maturity. Boxplots were constructed for these five variables, allowing for the observation of score concentration, outliers, and skewness. Additionally, basic descriptive statistics were calculated: mean, standard deviation, and IQR. Visualization and calculations allowed us to identify the most and least problematic dimensions describing open data maturity. Furthermore, a correlation analysis of the five variables studied was conducted to determine the degree of correlation between the dimensions. Pearson's linear correlation coefficient was used to calculate the correlation.

To answer the second research question, five cluster analyses were conducted using the k-means method. Because data were available for only 34 countries, it was decided not to use all variables simultaneously in the analysis. Such many variables with a relatively small number of observations could have produced unreliable results. Therefore, the first cluster analysis used five variables. Four of them addressed dimensions of open data maturity and were generalized indicators measuring these dimensions. The fifth measured open data maturity at the most general level (composite maturity). In this way, the following variables were selected for analysis: `policy_dimension`, `portal_dimension`, `quality_dimension`, `impact_dimension`, and `composite_maturity`. This stage of the research provided insight into the division of European countries in terms of the overall level of open data maturity.

Next, clustering was performed within each dimension using the indicators of each dimension as grouping variables. This stage of the research provided insight into the clustering of European countries within each of the four dimensions of open data maturity. In each case, the cluster analysis results were visualized in a two-dimensional space. To this end, two principal components were calculated using the Principal Component Analysis (PCA) method, using the grouping variables used in the given cluster analysis. This method created a two-dimensional space within which points representing each of the European countries studied were presented, divided into clusters. Furthermore, based on the calculated principal components, an additional variable was created summing the two principal components. The results were then sorted in descending order, and the countries with the top ten scores were filtered out. These countries were considered countries worth emulating.

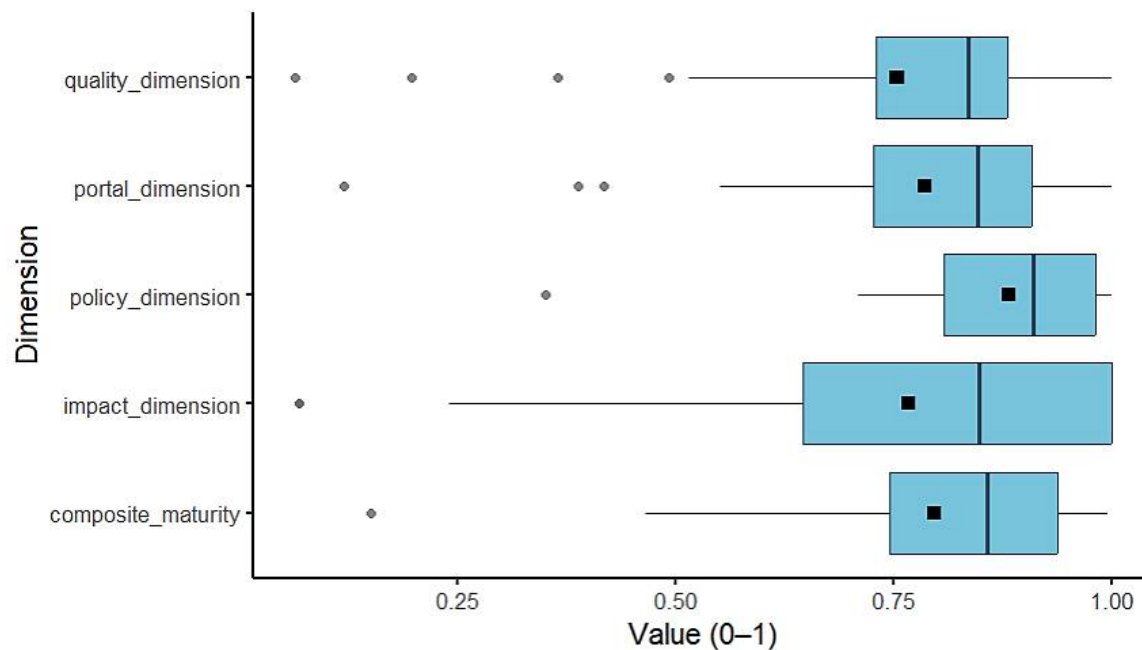
Three criteria were used to determine the number of clusters, using variables from the most general cluster analysis. The number of clusters determined there was used in all other analyses. This decision was made to facilitate comparison of clusters obtained using different grouping variables.

All calculations were performed in the R environment using both core and dedicated packages. Packages particularly important for the analyses include `tidyverse`, `psych`, and `ggplot2`.

4. Results

4.1. Distribution of open data maturity dimensions

To answer the initial research questions, distribution graphs of the studied indicators were created. The results are presented in Figure 1.



Note: the square indicates the average, the circles indicate outliers.

Figure 1. Distribution of open data maturity dimensions.

Source: own study.

Analysis of this figure indicates that all dimensions are characterized by a relatively high mean (above 0.75), left skewness, indicating a concentration of results at high values, and the presence of outliers with low values. The best results belong to the Policy dimension. This dimension is characterized by the highest mean (mean = 0.882) and moderate dispersion (sd = 0.130, IQR = 0.174). This means that meeting the requirements in this dimension is relatively easiest for the countries surveyed. Lower averages are found for the Portal (mean = 0.786), Quality (mean = 0.754), and Impact (mean = 0.768) dimensions. The Portal and Quality dimensions have relatively low dispersion. In turn, the Impact dimension has a large scatter of results (sd = 0.269, IQR = 0.353). This means that for the countries surveyed, meeting the requirements in these three dimensions is relatively the most difficult. Furthermore, countries differ significantly in terms of Impact.

To determine how the discussed dimensions are correlated, a correlation matrix was created and visualized. The results are presented in Figure 2.

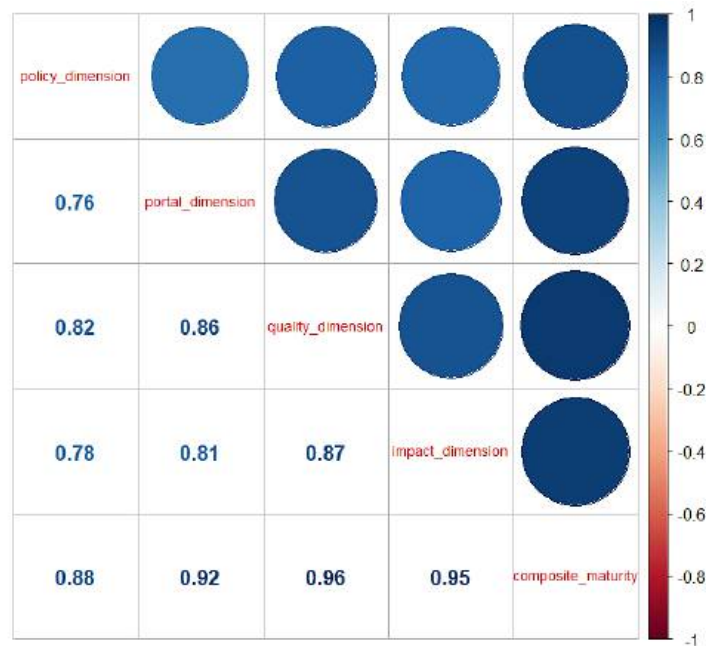


Figure 2. Correlation matrix of variables selected for cluster analysis.

Source: own study.

It shows very high correlations between variables. The Quality dimension correlates particularly highly with the Policy, Portal, and Impact dimensions. The highest correlations are found for Composite Maturity. However, this is due to the fact that this dimension is calculated from the other four dimensions.

4.2. Cluster analysis - selection of the number of clusters

To answer the second research question regarding the stratification of countries in terms of open data maturity, a k-means cluster analysis was conducted.

To determine the number of clusters, the WCSS, Caliński-Harabasz, and average silhouette criteria were used. The results are presented in Figures 3-5.

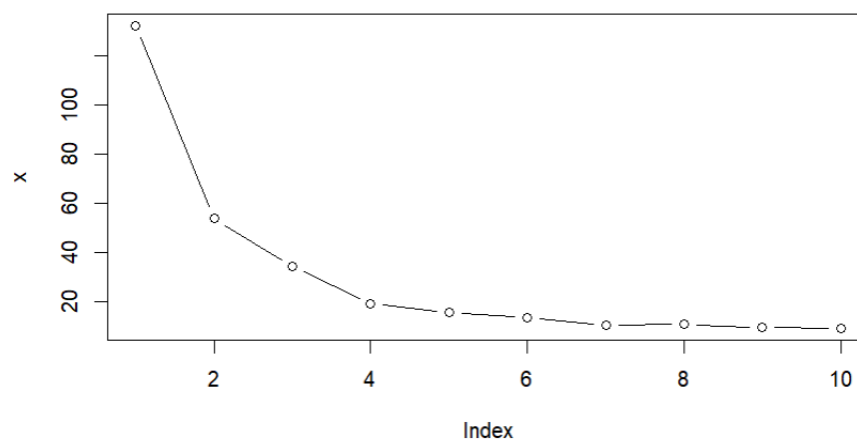


Figure 3. Scree plot illustrating the identification of the optimal number of clusters using the elbow method.

Source: own study.

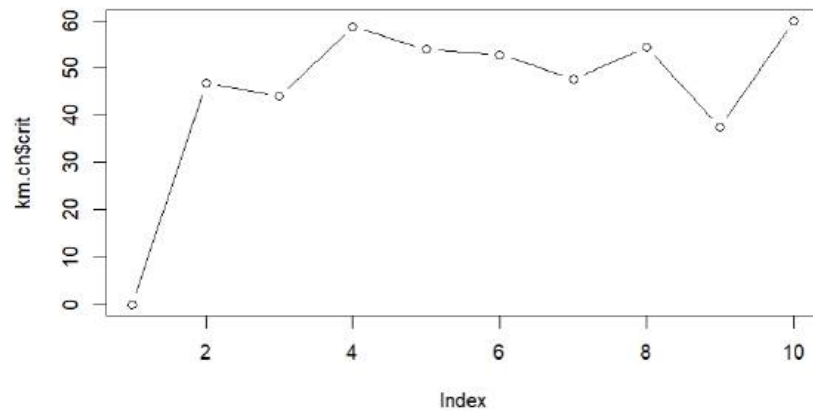


Figure 4. Determination of the optimal number of clusters based on the Calinski-Harabasz criterion.

Source: own study.

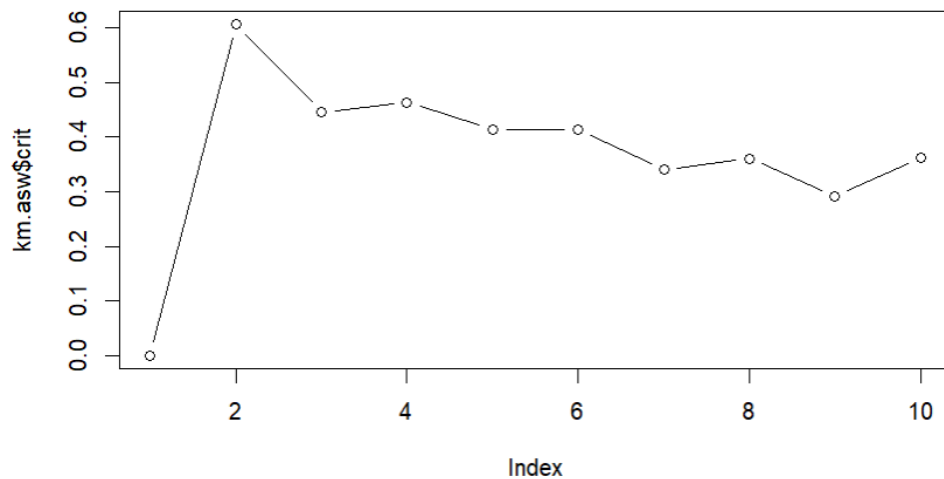


Figure 5. Determination of the optimal number of clusters based on the average silhouette criterion.

Source: own study.

The WCSS and average silhouette criteria indicated that two clusters were the optimal number. The Calinski-Harabasz criterion indicated 10 clusters as optimal. Ultimately, however, the decision was made to divide the studied countries into two clusters.

Cluster analysis based on general dimensions

After determining the optimal number of clusters, the analysis began. A k-means cluster analysis was performed, and a cluster number was assigned to each country in the data frame. The results were presented in a 2D graph, with the axes representing the principal components obtained using Principal Component Analysis (PCA). Therefore, this analysis was performed using varimax rotation. The results are presented in Figure 6.

	RC1	RC2
policy_dimension	0.450	0.888
portal_dimension	0.873	0.376
quality_dimension	0.799	0.530
impact_dimension	0.796	0.500
composite_maturity	0.814	0.580
SS loadings	2.90	1.797
Proportion Var	0.58	0.359
Cumulative Var	0.58	0.939

Figure 6. Principal Component Analysis results.

Source: own study.

This figure shows that reducing the five variables studied to two principal components explains 94% of the data variability. Four of the studied variables are correlated with the first component: portal dimension, quality dimension, impact dimension, and composite maturity. The policy dimension is correlated with the second component.

The obtained results were considered acceptable as 2D graph axes, and the cluster analysis results are presented in their arrangement (Figure 7). Analysis of Figure 7 indicates that most of the 34 countries studied demonstrate high open data maturity. These countries are classified as “cluster blue”. This cluster is characterized by high values on the RC1 and RC2 axes, representing the principal components obtained from the PCA results. Cluster named “red bluster” includes six examined countries characterized by lower scores on the RC1 and RC2 axes. There is one outlier in this cluster: Bosnia and Herzegovina, which is characterized by exceptionally low indicators in the field of open data maturity.

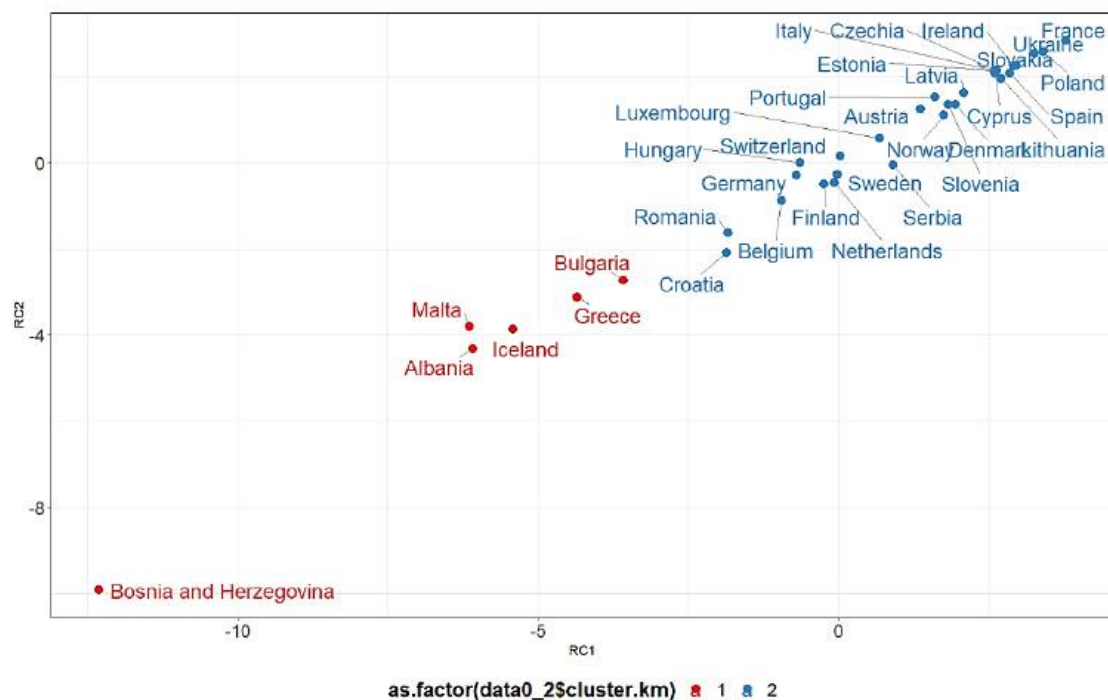


Figure 7. Cluster analysis results based on dimensions of policy, portal, quality, impact and composite maturity.

Source: own study.

To further explore both clusters, boxplots were created for each of the five variables, broken down by cluster (Figure 8). This confirms the high scores for the individual dimensions of “blue cluster”. Furthermore, it indicates that for “red cluster”, the most problematic dimensions are Impact and Quality. “Red cluster” is characterized not only by low mean values but also by a large dispersion of scores across these two dimensions. The least problematic dimension is Police. These conclusions are consistent with the previously presented analysis of the distributions of these dimensions.

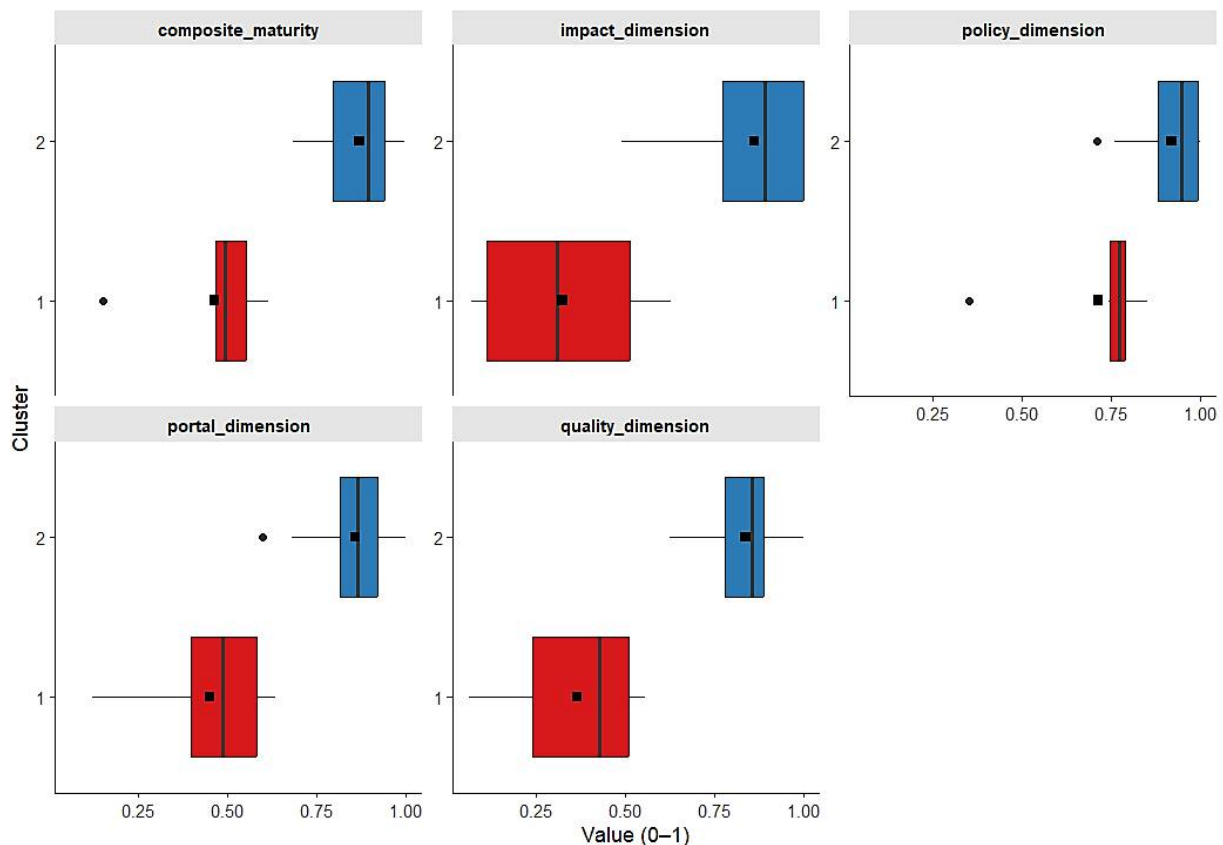


Figure 8. Comparison of open data maturity by two clusters.

Source: own study.

Cluster analysis in individual dimensions

Using the methodology applied for cluster analysis on the general dimensions of open data maturity, four additional cluster analyses were performed, each based on indicators describing a given dimension. This method utilized four indicators in the Policy dimension, five indicators in the Portal dimension, four indicators in the Quality dimension, and eight indicators in the Impact dimension. The results of these analyses are presented in Figures 9-12.

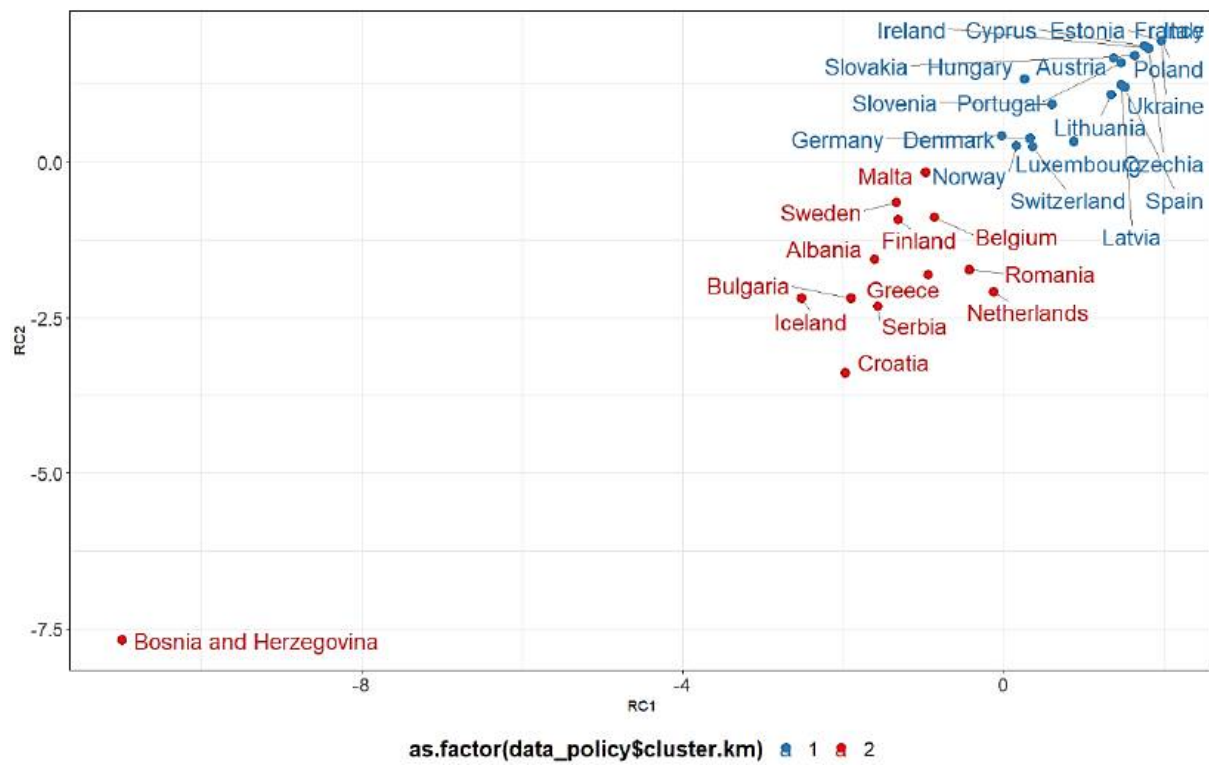


Figure 9. Clusters in Policy dimension of open data maturity.

Source: own study.

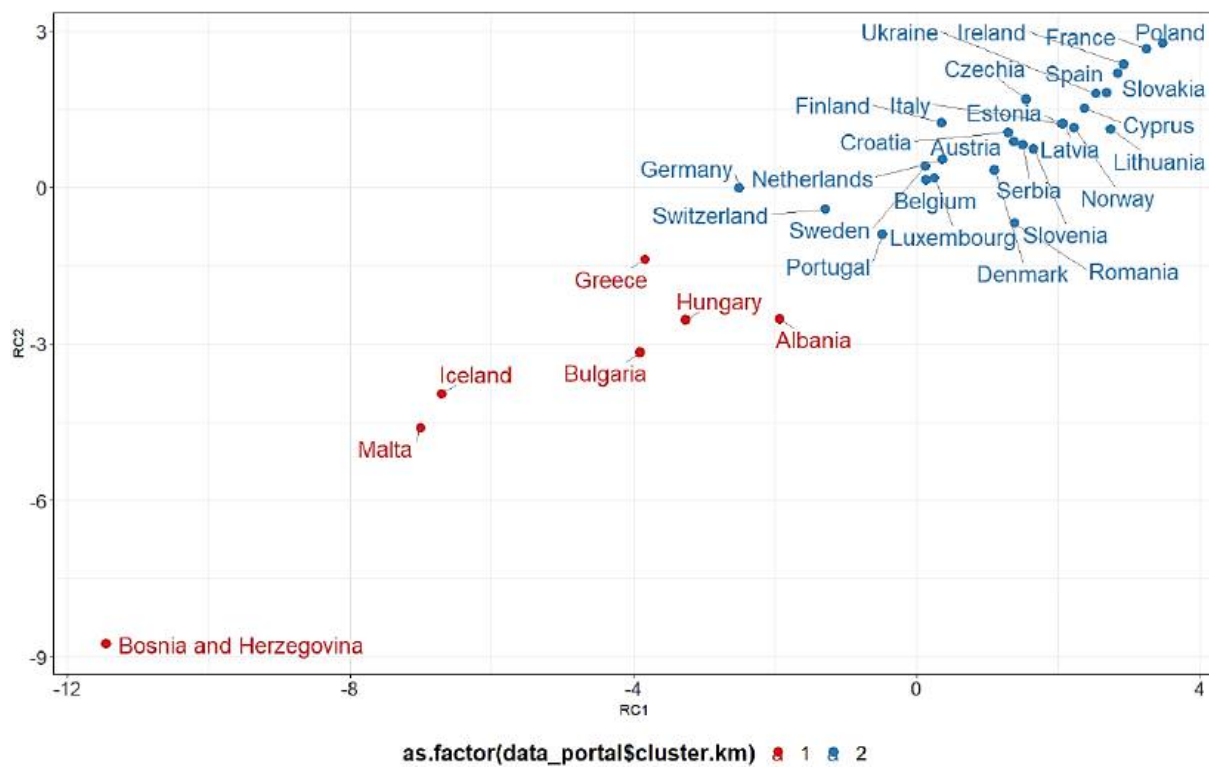


Figure 10. Clusters in Portal dimension of open data maturity.

Source: own study.

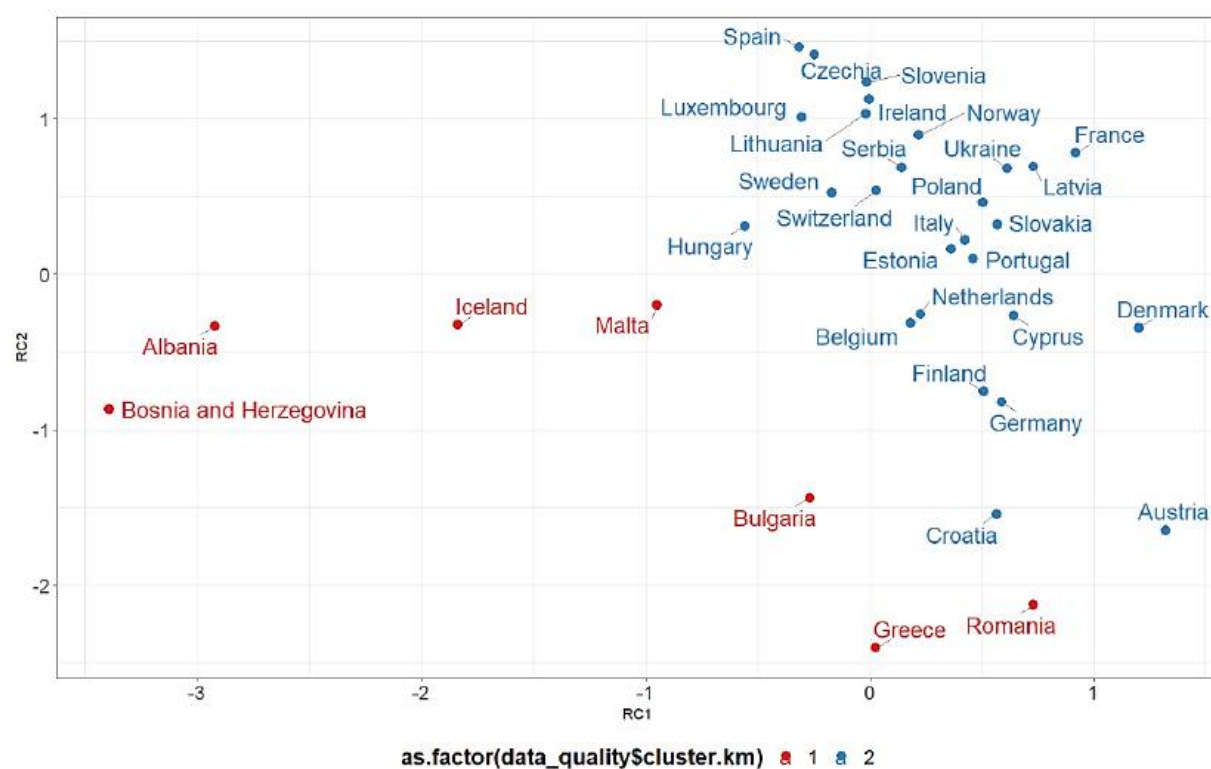


Figure 11. Clusters in Quality dimension of open data maturity.

Source: own study.

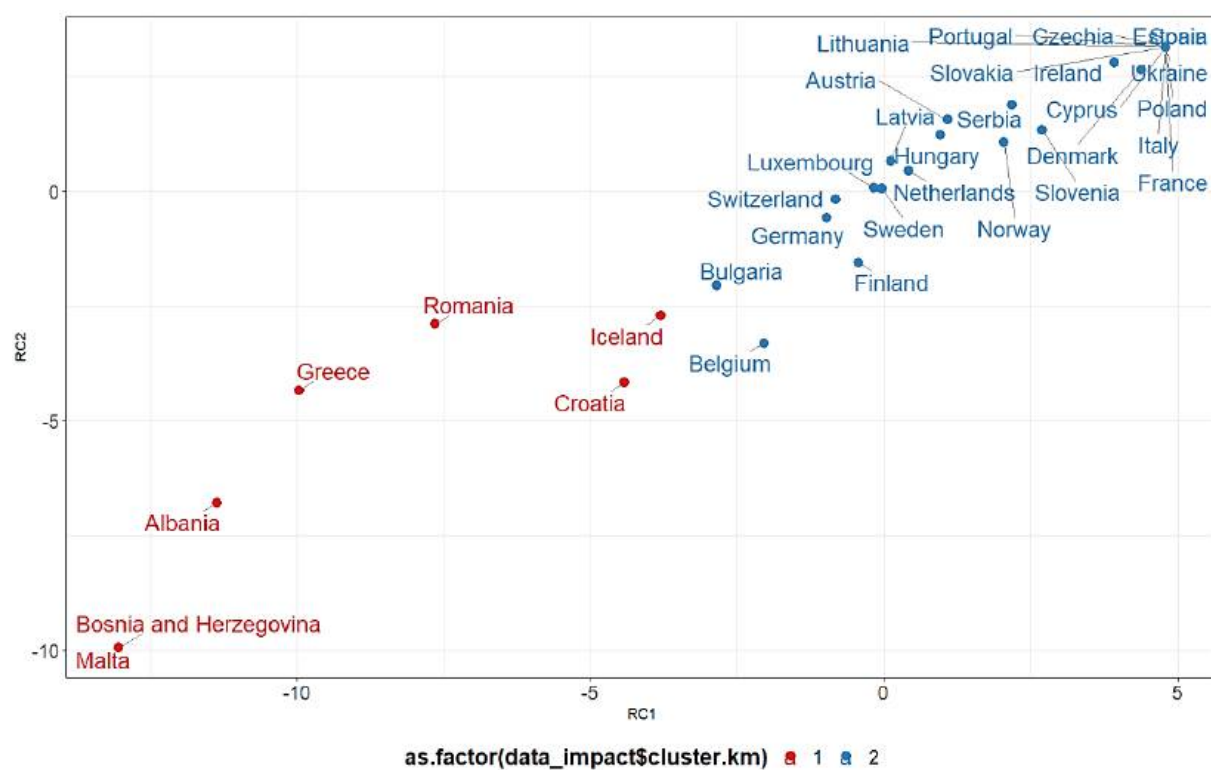


Figure 12. Clusters in Impact dimension of open data maturity.

Source: own study.

It was assumed that countries would be grouped into two clusters each time, as in the case of cluster analysis performed on four dimensions and the Composite Maturity variable. For the Policy dimension, the cluster associated with the lower maturity level encompassed 13 countries. For the remaining dimensions, the lower maturity cluster encompassed 7 countries.

Since we assumed we were looking for countries with the best results, we used the scores of two principal components (RC1 and RC2) calculated for each country in each dimension. After summing RC1 and RC2, we sorted the results in descending order and filtered out the 10 countries with the highest scores in each dimension. The top ten most advanced countries in each dimension are listed in Table 1. The most frequently occurring countries are: France, Poland, Spain, Cyprus, Ireland, Ukraine, Slovakia, Czechia, Estonia, and Lithuania (see. Figure 13).

Table 1.

Ranking of the 10 countries with the highest scores in each dimension of open data maturity

Policy dimension	Portal dimension	Quality dimension	Impact dimension	5 main dimensions
Estonia	Poland	France	Czechia	France
France	France	Latvia	Estonia	Poland
Italy	Ireland	Ukraine	Spain	Ukraine
Poland	Spain	Slovenia	France	Slovakia
Ukraine	Slovakia	Czechia	Italy	Ireland
Czechia	Ukraine	Spain	Cyprus	Spain
Ireland	Cyprus	Ireland	Lithuania	Czechia
Cyprus	Lithuania	Norway	Poland	Italy
Slovakia	Norway	Lithuania	Portugal	Estonia
Portugal	Estonia	Poland	Slovakia	Cyprus

Source: own study.

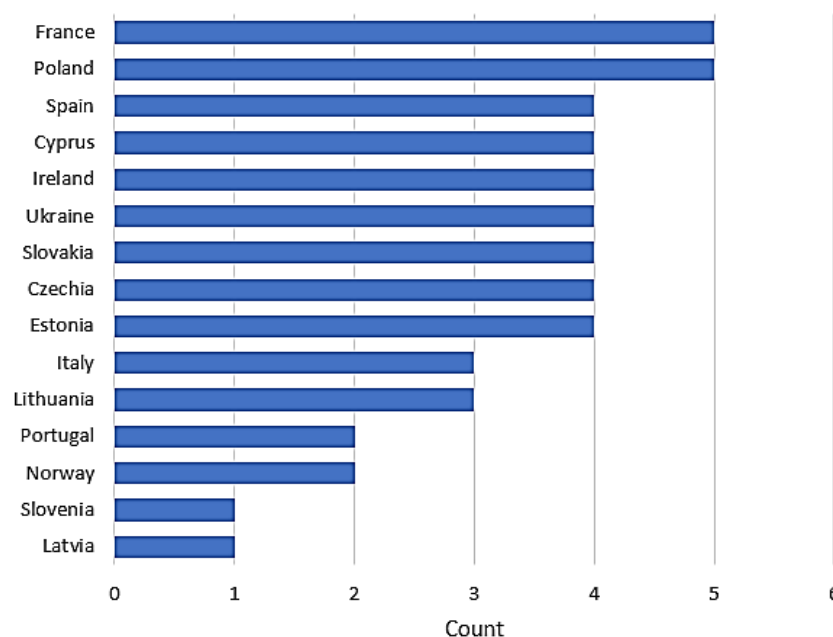


Figure 13. Frequency of a country's appearance in dimension rankings.

Source: own study.

5. Discussion

The presented research results indicate that the countries studied are characterized by relatively high open data maturity. However, this maturity varies across four dimensions. Achieving high maturity in the Policy dimension was the easiest for countries, while achieving it in the remaining three dimensions was more challenging. Additionally, the Impact dimension shows the greatest variation in open data maturity across countries. These results are consistent with the studies presented in (Blank, 2020) and (Page et al., 2023).

Cluster analysis revealed that, using the general dimensions, 11 countries with the highest scores on open data maturity dimensions can be identified. These are France, Poland, Spain, Cyprus, Ireland, Ukraine, Slovakia, Czechia, Estonia, and Lithuania. We recommend these countries as examples to follow. Our results are consistent with, but not identical to, those in this work (Page et al., 2023).

We also identified countries with lower open data maturity, including Albania, Bosnia and Herzegovina, Bulgaria, Greece, Iceland, and Malta. Using dimensions such as Portal, Quality, and Impact, we also include Croatia, Hungary, and Romania in these six countries. Our results are consistent with the work of (Page et al., 2023).

The most restrictive dimension in terms of grouping the surveyed countries in terms of open data maturity was the Policy dimension. This dimension yielded the best results and therefore identified as many as 13 countries with lower maturity. In our opinion, this dimension should be considered an outlier. This is indicated not only by the higher scores on this dimension but also by the results of the principal component analysis, which clearly showed that this dimension should be treated as a separate principal component.

While we identified 11 countries as clear leaders in open data maturity, it's worth emphasizing that the group of countries achieving a high level of data maturity was much broader across all analyzed dimensions. This demonstrates that European data ecosystems are gradually maturing not only in a few leading countries but across the entire region. This broad "high cluster" indicates that European Union countries are consistently developing a common infrastructure and data sharing culture, which is the foundation for building a European data community. The convergence of maturity levels across so many countries signifies the growing harmonization of standards, processes, and policies regarding public data. In practice, this translates into an increased willingness to leverage data as a strategic resource that supports both digital and green transformations. As a result, it's clear that the drive to open data is becoming a key element of European development policy, and a high level of data maturity is no longer the domain of a few leaders but is becoming a hallmark of an increasingly large part of Europe.

6. Conclusion

The results indicate that, overall, open data maturity in European countries is high. However, the countries analyzed can be divided into two groups with different levels of maturity. This division persists across all dimensions of open data maturity.

The group of countries with high open data maturity is larger. Additionally, our research identified eleven European countries leading the way in open data maturity. Dividing countries into two groups with different levels of maturity suggests that strategies and interventions should be tailored to their current level of development. The stable division into groups suggests that systematically monitoring open data maturity and benchmarking against leaders can help countries more effectively identify gaps and assess the effectiveness of implemented changes.

Countries with lower maturity require basic actions to strengthen data infrastructure and organization, while more advanced countries can focus on increasing data quality, interoperability, and reuse.

The countries identified in the study as leaders in open data maturity can serve as benchmarks for other countries. Analyzing the solutions these countries employ (in terms of data management, standards, sharing methods, and user support) can accelerate the development of open data systems in countries with lower maturity.

Research limitations and future directions

Because the dataset contained relatively few observations, the cluster analysis was performed using a reduced set of grouping variables. The study focused exclusively on European countries, so future research could expand by comparing the open data maturity of European nations with countries from other regions.

As directions for further research, we suggest that it would be worthwhile to examine the use of open data in individual countries indicated as open data maturity leaders. Such analyses would provide broad insight into how open data is used and what values it generates. Analyses in this context would be an interesting extension of the issue of open data maturity.

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