

SPATIAL DIVERSITY OF ENVIRONMENTAL INVESTMENTS IN POLISH REGIONS

Marcin SPYCHAŁA

Poznań University of Economics and Business; marcin.spychala@ue.poznan.pl, ORCID: 0000-0002-3860-303X

Purpose: The aim of this article is to present the spatial differentiation of environmental investments across Polish counties. Furthermore, the study grouped the surveyed units based on the results of implemented environmental investments.

Methodology: This study presents the scope of environmental investments based on 20 indicators derived from public statistical data from the Local Data Bank of the Central Statistical Office. The indicators included in the study cover five areas: waste management, wastewater management, pollution reduction and resource consumption, biodiversity, and the tangible effects of investments. The scope of environmental investments was presented based on a synthetic measure showing the taxonomic distance of a given district from the established development pattern.

Findings: The research presented the spatial diversity of environmental investments in 380 counties in Poland. The results of the study are presented by voivodeship. The surveyed counties were grouped based on the synthetic indicator, its mean value and standard deviation.

Originality/value: This article presents the results of extensive research conducted on a group of 380 entities, based on 20 indicators that uniquely illustrate the environmental orientation of investments in Polish counties. The study results can serve as a source of inspiration for EU institutions in formulating environmental strategies covering the entire European Union.

Keywords: environmental investments, counties, distance from the pattern, Hellwig reduction, grouping.

Category of the paper: Research paper.

1. Introduction

In the face of ongoing climate change, environmental degradation, and growing regulatory requirements for environmental protection, environmental investments are playing an increasingly important role in the development policies of European Union member states, including Poland. These activities constitute a key element in implementing the concept of sustainable development, combining ecological goals with economic development and improving the quality of life of society (Tukker, 2004). Contemporary conditions for socio-

economic development are increasingly determined by the need to reduce the negative impact of human activity on the natural environment (Yang, 2023). Consequently, environmental investments constitute a key instrument for implementing environmental protection policy and the principles of sustainable development, both at the level of the European Union and individual member states (Tietenberg, Lewis, 2023).

In Poland, environmental investments encompass a wide range of projects, such as the development of renewable energy sources, modernization of water and sewage infrastructure, improvement of energy efficiency, waste management, and protection of biodiversity. The implementation of these activities is supported by both national funds and European Union funds, which have long been a significant source of financing for ecological transformation. Despite the growing importance of environmental initiatives, a research gap has been identified in the literature regarding the importance of environmental investments in local development. To fill this gap, the author of this study decided to analyze the spatial diversity of environmental investments across Polish counties.

This paper will present the spatial differentiation of environmental investments across all 380 counties in Poland, based on 20 indicators. The basis for calculating the indicators will be statistical data for the period 2015-2024 from the Local Data Bank of the Central Statistical Office. The scope of environmental investments in individual counties will be presented based on a synthetic measure representing the taxonomic distance of a given county from an established investment scope benchmark. This paper aims to test the hypothesis that highly industrialized counties with high economic potential lead in environmental investments, while less environmental investments are implemented in regions with a lower degree of industrialization and urbanization.

The main goal of this study is to identify and assess the spatial diversity of environmental investments across Poland's counties. The adopted analysis scale (NUTS-4) captures local specificities, which often remain invisible in analyses with a higher level of aggregation (voivodeship). Achieving the main goal required a multidimensional comparative analysis based on a set of 20 partial indicators reflecting key components of environmental protection, including water and sewage management, air and climate protection, and waste management.

To eliminate the influence of the size of the studied units, raw statistical data from the Central Statistical Office's Local Data Bank were subjected to a relativization procedure (by relating them to the number of inhabitants or the area of the unit). The next stage of the research involved the application of taxonomic methods, including grouping procedures, which allowed the identification of types of counties with similar investment profiles. This approach allows not only for a description of the actual state of affairs but also for verification of whether clusters (agglomerations) of units with similar levels of pro-ecological activity exist in the Polish geographic space, which is associated in the literature with the neighbourhood effect and the diffusion of good practices (Churski et al., 2021).

This article will first review the literature on the scope and importance of environmental investments. Next, the research methodology will be described, along with a description of each stage of the research procedure. The obtained results will then be discussed in detail. Finally, the final section will outline conclusions and recommendations regarding the spatial differentiation of environmental investments across Polish counties.

The scientific contribution of this article consists in: developing a multi-criteria ranking of poviats based on an original set of 20 indicators, identifying spatial investment clusters using taxonomic methods, and verifying the hypothesis of progressive spatial polarization between industrial growth centres and peripheral areas in terms of environmental infrastructure.

2. The importance and scope of environmental investments – Literature Review

Environmental investments constitute a key analytical category in contemporary research on sustainable development and environmental economics. Their importance is growing with the increasing anthropogenic pressure on the natural environment and the increasing internalization of environmental costs in the decision-making processes of public and private entities. Despite widespread research interest, the concept of environmental investments lacks a single, universally accepted definition, reflecting the interdisciplinary nature of the subject and the evolution of theoretical approaches to environmental protection (Fiedor, 2010; Ocko, Hamburg, 2022).

In the classical approach to environmental economics, environmental investments are defined as long-term capital expenditures incurred to limit environmental degradation, reduce pollution, or restore the quality of natural resources to a socially acceptable level (Pearce, Turner, 1990; Anderson, 2024). These authors point out that environmental investments are a response to market failure in the allocation of environmental goods, the value of which is not fully reflected in the pricing mechanism, and their implementation favors the internalization of negative externalities.

The literature on the subject emphasizes the technological dimension of environmental investments. For a long time, *end-of-pipe* investments dominated, involving the installation of emission-reducing devices at the final stage of the production process (OECD, 2000). However, with the development of cleaner production and eco-innovation concepts, integrated investments encompassing technological, organizational, and product changes that lead to reduced environmental pressures at the source are gaining increasing importance (van den Bergh, 2013; Rulli, Saviori, D'Odorico, 2013).

The specificity of environmental investments lies in their limited ability to generate direct financial benefits, while simultaneously generating high potential for social and ecological benefits (Żylicz, 2004; Song, Zou, Liang, 2023). These benefits often constitute public or common goods, justifying government intervention. As Stiglitz (2000) emphasizes, without appropriate public policy instruments, the level of private environmental investments remains below the socially optimal level. Consequently, their effectiveness is assessed using extended analytical methods, particularly cost-benefit analysis that takes into account non-market effects.

The importance of environmental investments extends beyond immediate ecological goals and also encompasses macroeconomic aspects. These investments contribute to reducing the social costs of environmental degradation, such as health costs, loss of natural capital, and reduced labor productivity (Stern, 2007). Failure to invest in this area leads to the accumulation of so-called ecological debt, which in the long term may limit the development potential of the economy (Fiedor, 2002; Rogall, 2010).

The scope of environmental investments is broad and encompasses both infrastructure and intangible assets. The most common investments include those aimed at air protection, water and sewage management, waste management, soil protection, and biodiversity protection, as well as investments related to climate change mitigation and adaptation (GUS, 2023). Investments in environmental management systems, research and development of green technologies, and the development of environmental competencies are also playing an increasingly important role (OECD, 2009).

Recent literature also analyzes environmental investments in the context of economic competitiveness and innovation. According to Porter's hypothesis, appropriately designed environmental regulations and accompanying investments can stimulate innovation and lead to increased business efficiency (Porter, van der Linde, 1995). In this perspective, environmental investments are an important element in transforming the economy towards a low-emission and resource-efficient model (OECD, 2011; European Commission, 2019; Bhuiyan, Huang, de Villiers, 2021).

Local governments play a crucial role in implementing environmental investments, as they operate at a level that directly impacts residents' living conditions and the state of local environmental resources. The literature emphasizes that the scope of environmental investments undertaken by local government units is closely linked to their statutory competences and responsibility for providing environmental public services (Wang, Tian, Zheng, 2025). These investments primarily focus on the development and modernization of municipal infrastructure, including water and sewage management systems, waste management, and air quality, which constitute the primary areas of local government influence (Hamel, Tan, 2022).

Another significant area of local government investment activity is projects aimed at improving energy efficiency and reducing pollutant and greenhouse gas emissions. These include, among others, thermal modernization of public buildings, modernization of

heating systems, development of renewable energy sources, and investments in sustainable public transport (OECD, 2011; Central Statistical Office, 2023). Local governments are also increasingly engaging in climate change adaptation initiatives, such as investments in green and blue infrastructure, stormwater retention, and protection of green areas (Manero, Mach, 2023).

The scope of environmental investments implemented by local governments also encompasses planning and organizational activities, including the development and implementation of local environmental strategies, low-emission economy plans, and environmental monitoring systems. Although these investments are often intangible, the literature indicates that they play a key role in ensuring the coherence and effectiveness of local environmental policy and in increasing the absorption capacity of external funds allocated for environmental purposes (Fiedor, 2010; Rogall, 2010).

Contemporary economic analysis redefines the role of environmental investments, embedding them within the paradigm of sustainable development. In this approach, natural capital is not treated solely as an exploitable resource, but as a key determinant of exogenous and endogenous growth processes (Pearce, Turner, 1990). Investments in ecological infrastructure (e.g., water and sewage management or renewable energy sources) constitute a significant element in shaping the investment and settlement attractiveness of regions. According to the *Environmental Kuznets Curve (EKC)*, initial economic growth generates pressure on the environment, but after reaching a certain level of prosperity (a tipping point), pro-ecological investments become a condition for further economic expansion (Grossman, Krueger, 1995; Domański, 2005).

From the perspective of local development, environmental protection expenditures act as a stimulant for regional innovation. According to Porter's hypothesis, rigorous environmental standards and the resulting investments in modern technologies (so-called *eco-innovations*) may force enterprises to improve resource efficiency, which in the long term builds the competitive advantage of territorial units (Porter, van der Linde, 1995). In Poland, researchers emphasize that the spatial differentiation of these investments is closely correlated with the availability of European Union structural funds, which constitute the main development stimulus for peripheral regions, enabling them to converge with more urbanized areas (Guzal-Dec, 2020).

Furthermore, environmental investments should be interpreted through the lens of public goods theory and their impact on quality of life. Improving air quality or reclaiming degraded areas increases land rents and attracts human capital, which is crucial in building regional resilience to demographic crises (Stanny, Czarniecki, 2011). Lack of appropriate investment in this area leads to the accumulation of negative externalities, which is identified in the literature as a barrier limiting the development potential of so-called "lagging regions" (Wojewódzka-Król, 2015).

Empirical analyses of the diversity of environmental protection expenditures in Poland indicate a persistent disproportion between the regions of Western Poland and the so-called Eastern Wall. Research by Rosik et al. (2015) demonstrates that the proximity of foreign markets and innovation centers determines the higher dynamics of pro-ecological investments in voivodeships such as Greater Poland and Lower Silesia. Piontek (2020), in turn, points out that in regions with an industrial profile (Silesia), investments are reactive (remedial), while in tourist regions (Warmia-Masuria), they are proactive, focused on protecting landscape values.

Previous empirical studies on the diversity of environmental protection expenditures in Poland have focused mainly on analyzing the correlation between the size of investments and the level of economic development measured by GDP (Mickiewicz et al., 2021) or on assessing the efficiency of absorption of funds from structural funds (Klepacki et al., 2021). However, most available studies are based on data aggregated to the national or regional level (NUTS-2), which often obscures significant intra-voivodeship differences and local conditions specific to smaller territorial units.

This study fills an identified research gap in two respects:

- **Timeliness:** While existing literature largely focuses on the 2014-2020 financial perspective, this article analyzes investment dynamics in the post-pandemic period, taking into account new challenges arising from the energy crisis and the acceleration of the digital and green transformation.
- **Multidimensional approach:** Unlike studies focusing on a single component (e.g., wastewater management alone), this study compares various investment categories, allowing for the identification of regional pro-ecological specializations.

The lack of broad, comparable research in this context justifies addressing this issue and allows for the formulation of new recommendations for environmental investments.

In summary, the analysis of the definition, significance, and scope of environmental investments indicates their complex and multidimensional nature. In the literature, these investments are viewed not only as an instrument for environmental protection but also as a crucial element of modern development policy, integrating economic, ecological, and social goals. The lack of a uniform definition of environmental investments reflects the interdisciplinary nature of this category and the evolution of theoretical approaches—from classical environmental economics, through institutional approaches, to contemporary concepts of green growth and sustainable finance.

3. Characteristics of the research procedure – Methodology

To examine the spatial diversity of environmental investments across Polish counties, a synthetic measure of distance from the benchmark was used (Spychała, 2023). The research procedure consisted of four successive stages:

1. variable selection – construction of a geographic information matrix,
2. reduction of the multi-feature space,
3. determination of the results of environmental investments using the synthetic measure of distance from the benchmark,
4. classification of counties into four groups: based on the standard deviation and the mean value of the synthetic measure.

In the first stage of the research procedure, a geographic information matrix was constructed based on 20 indicators (Table 1), which were used to determine the scope of environmental investments in the counties. The indicators included in the study concern the results of environmental investments achieved cumulatively up to and including 2024 and concern five areas: waste management, sewage management, pollution reduction and resource consumption, biodiversity, and the tangible effects of the investments (Table 1). After determining the matrix, Pearson linear correlation coefficients were calculated between all the studied output indicators. It is crucial that the indicators selected for the synthetic measure of distance from the benchmark are weakly correlated with each other. This increases the information capacity of these indicators.

Table 1.

Indicators included in the analysis of the scope of environmental investments

Scope of the study	Indicators
Waste management (3 variables)	selectively collected waste in relation to total waste; share of waste subject to recovery; maintaining order and cleanliness - number of waste bins per 100 inhabitants.
Wastewater management (4 variables)	percentage of the population using sewage treatment plants; sewage treatment plants with increased nutrient removal as a percentage of the population; pollutant loads in sewage discharged into waters or into the ground per 1000 inhabitants; length of the sewage disposal network (in km per 1000 inhabitants).
Reducing pollution and resource consumption (4 variables)	asbestos-containing products remaining to be disposed of in relation to the total inventoried volume of asbestos-containing products (destimulant); water consumption per capita (destimulant); electricity consumption per capita (destimulant); capacity of installed devices and installations to reduce dust and gaseous air pollution (in tonnes per year per 1000 inhabitants).
Biodiversity (3 variables)	planting of trees and shrubs per 1 km ² of area; share of legally protected areas in the total area; afforestation in ha per 1000 inhabitants.
Material effects of environmental investments (6 variables)	bicycle paths per 100 km ² ; number of apartments in which heat sources were replaced per 1000 inhabitants; investment outlays in enterprises per 1 inhabitant; length of flood embankments (in km per 1000 inhabitants); daily capacity of water treatment plants (in m ³ per 1000 inhabitants); share of residential buildings for which the primary energy indicator EP was demonstrated as part of the energy performance of buildings.

Source: own research.

The created matrices of Pearson's linear correlation coefficients were the basis for reducing the output variables using Z. Hellwig's method – that is, for extracting diagnostic features – those indicators that will be included in the subsequent research procedure (Miłek, 2018). In Z. Hellwig's feature reduction method, the diagnostic feature is the indicator whose sum of the absolute values of the correlation coefficients with the remaining features is the highest (it is then called the central feature). Then, variables for which the value of the correlation coefficient with the diagnostic feature is higher than the critical value determined based on the following formula are eliminated (Neumayer, 2000):

$$r^* = \sqrt{\frac{(t^*)^2}{n-2+(t^*)^2}} \quad (1)$$

where:

r^* – critical value of the Pearson linear correlation coefficient,

t^* – value of Student's t-statistic,

n – number of output variables.

As a result of implementing this method, variables that are statistically significantly correlated with the diagnostic feature (called satellite features) are eliminated. In each subsequent step, the correlation matrix is reduced by the central feature and the satellite features. The Z. Hellwig method is repeated, obtaining new reduced correlation matrices, until the set of features is exhausted or isolated features are identified (Tester, Langridge, 2010).

In the next step of the research process, the pattern and anti-pattern of environmental investment scope were determined. The maximum standardized values of individual diagnostic features were considered the pattern, while their minimum values were considered the anti-pattern (Spychała, 2023). In the next step, the taxonomic distance of each studied county from the environmental investment pattern was determined based on the following formula (Cheng, Feng, 2023):

$$d_{i0} = \sqrt{\sum_{j=1}^m (z_{ij} - z_{0j})^2} \quad (2)$$

where:

d_{i0} – taxonomic distance of the district and from the adopted investment scope pattern,

z_{ij} – standardized value of indicator j for district I,

z_{0j} – standardized value of the j indicator for the investment scope pattern.

In the next stage of the research procedure, a synthetic measure was determined for each district, which was an indicator of the scope of environmental investments in a given unit. The synthetic measure was calculated based on the following formula (Neumayer, 2000):

$$v_i = 1 - \frac{d_{i0}}{d_0} \quad (3)$$

where:

v_i – a synthetic measure of the scope of environmental investments in the district I,

d_{i0} – taxonomic distance of the district and from the adopted investment pattern,

d_0 – taxonomic distance of the pattern from the anti-pattern of investments.

The synthetic index of environmental investment scope ranges from 0 to 1, with the higher the value, the higher the level of the phenomenon being studied. Based on the calculated synthetic indices, a ranking of 380 counties was established and then divided into four groups: very high (counties with the highest synthetic index value, exceeding the average value of the synthetic measure calculated for all counties plus the standard deviation – Group I), high (counties next in the ranking whose index value exceeded the average – Group II), average (counties whose synthetic index value was below the average – Group III), and low (counties whose synthetic index value was below the average minus the standard deviation – Group IV) in environmental investment scope.

4. Results of the conducted research procedure

The research procedure presented the spatial diversity of environmental investments in Poland across 380 counties (Figure 1). In the studied group of units, the value of the synthetic measure representing the scope of environmental investments ranged from 0.121 to 0.336, with the lowest value recorded in Lubin County and the highest in Racibórz County (Table 2).

Racibórz County has become a leader in implementing environmental investments primarily because it has consistently, and for many years, implemented large-scale initiatives that combine environmental protection with the safety of its residents and economic development. A prime example is the Racibórz Dolny dry flood control reservoir – one of the largest hydrotechnical investments in Poland, protecting not only the county but the entire Oder River basin from flooding. Thanks to this investment, the county has become a model for adapting to extreme weather events. Additionally, a wind farm project with a capacity of over 40 MW is underway in Racibórz County, which will contribute to reducing CO₂ emissions and improving air quality. Furthermore, Racibórz County is very successful in securing EU funds for environmental investments. The county does not focus on a single area, but rather works in a multifaceted manner: improving air quality (through the replacement of heat sources and anti-smog measures), protecting nature and biodiversity (Łęczczok nature reserve), and implementing investments in sustainable transport and water management. This shows long-term thinking, not single, “point” investments.

Scope of environmental investments in Polish counties (synthetic index value)

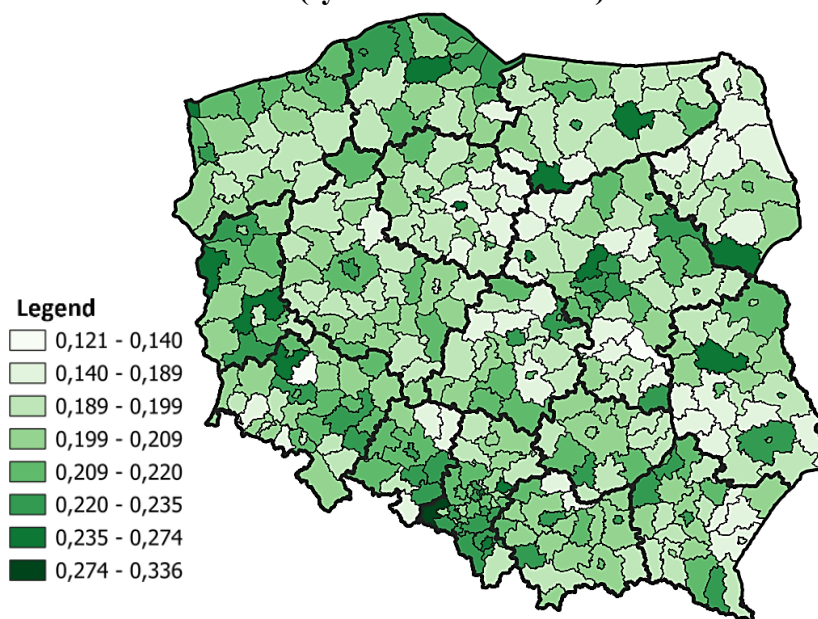


Figure 1. Spatial diversity of environmental investments in the district system.

Source: own research.

Płock's high ranking stems from its consistently implemented, long-term environmental policy, which combines environmental protection with economic development and improved quality of life for its residents. The city's initiatives are characterized by a comprehensive approach and the effective use of modern technological and financial solutions. A significant factor influencing Płock's position is the development of investments related to energy transition. The presence of large-scale industry, particularly the petrochemical sector, promotes the implementation of innovative technologies that reduce pollutant emissions and increase energy efficiency. These initiatives are consistent with sustainable development and climate policy. Investments in water and sewage management and the waste management system are also important areas. Modernization of technical infrastructure, development of selective waste collection, and protection of water resources, including the Vistula River ecosystem, contribute to improving the natural environment and the city's ecological safety.

Polkowice County's high ranking, in turn, may be the result of its consistent implementation of a sustainable development policy, based on leveraging the region's economic potential and effectively implementing modern pro-ecological solutions. Cooperation between local government and the industrial sector, as well as long-term strategic planning, are crucial here. One of the most important factors influencing Polkowice County's position is the presence of a strong industrial base. While the mining and processing industries generate significant environmental burdens, they also facilitate the implementation of advanced investments that mitigate negative environmental impacts. These include, among other things, the modernization of industrial facilities, the remediation of degraded land, and the implementation of technologies that reduce pollutant emissions into the air, water, and soil. Investments in water

and sewage management and the protection of water resources are also important areas of activity. Modernization of sewage treatment plants, expansion of the sewer network, and efforts to promote rational water management contribute to improving the natural environment and the region's ecological safety.

Table 2.

Counties with the highest and lowest synthetic index values

The highest and lowest values of the synthetic index					
MAX			MIN		
Place	County	Value	Place	County	Value
1	raciborski	0.336	380	lubiński	0.121
2	Płock	0.274	379	kozienski	0.140
3	polkowicki	0.260	378	brodnicki	0.175
4	mragowski	0.255	377	rypiński	0.176
5	Bielsko-Biała	0.255	376	moniecki	0.176
6	Dąbrowa Górnicza	0.252	375	krasnostawski	0.176
7	siemiatycki	0.252	374	zuroński	0.177
8	słubicki	0.250	373	pultuski	0.177
9	nowodworski	0.249	372	kolneński	0.177
10	zielonogórski	0.249	371	suwalski	0.178

Source: own research.

The detailed results of the study are presented in Table 3. It lists three counties with the highest synthetic index values and three counties with the lowest index values in each voivodeship. Large cities are relatively common among the counties with the highest index values. They have specific organizational, financial, and functional conditions that favor the implementation of costly and complex pro-environmental projects. Above all, large cities are characterized by greater financial capacity. Higher revenues enable the co-financing of environmental investments, which often require significant own contributions. This allows these cities to more effectively utilize EU and national funds. Another factor is the scale and concentration of environmental problems. Large urban centers experience higher traffic congestion, higher pollutant emissions, and greater demand for water, energy, and waste management systems. This necessitates intensive investment activities that simultaneously deliver significant and measurable environmental benefits. Better institutional and human resources also play a significant role. Large cities have specialized organizational units and staff experienced in planning, implementing, and settling environmental projects. This facilitates the preparation of documentation and the effective implementation of large-scale investments. Furthermore, large cities often serve as centers of innovation and technological development. Collaboration with universities, research institutes, and the private sector fosters the implementation of modern solutions in energy, transport, and water and sewage management, further strengthening their position as leaders in environmental protection.

Table 3.*Counties with the highest and lowest synthetic index values in the voivodeships*

Voivodeship	Counties with the highest index value			Counties with the lowest index value		
	1	2	3	1	2	3
Dolnośląskie	polkowicki	wrocławski	strzeliński	lubiński	kamiennog.	lwówecki
Kujawsko-pomorskie	Toruń	Bydgoszcz	tucholski	brodnicki	rypiński	toruński
Lubelskie	lubartowski	zamojski	Chełm	krasnostawski	hrubieszowski	kraśnicki
Lubuskie	słubicki	zielonogórski	gorzowski	Zielona Góra	wschowski	żarski
Łódzkie	Łódź	skierniewicki	Piotrków T.	piotrkowski	poddębicki	łowicki
Małopolskie	Kraków	Tarnów	suski	miechowski	proszowicki	nowotarski
Mazowieckie	Płock	nowodworski	Ostrołęka	kozienicki	żuromiński	pułtowski
Opolskie	kędzierz.-koz.	krapkowicki	strzelecki	oleski	kluczborski	głubczycki
Podkarpackie	Rzeszów	leski	mielecki	jarosławski	przemyski	przeworski
Podlaskie	siemiatycki	Białystok	Suwałki	moniecki	kolneński	suwański
Pomorskie	kartuski	Słupsk	Gdańsk	sztumski	bytowski	człuchowski
Śląskie	raciborski	Bielsko-Biała	Dąbrowa G.	zawierciański	lubliniecki	kłobucki
Świętokrzyskie	pińczowski	jędrzejowski	staszowski	ostrowiecki	włoszczowski	opatowski
Warmińsko-mazurskie	mragowski	działdowski	Olsztyn	nidzicki	nowomiejski	kętrzyński
Wielkopolskie	Poznań	poznański	słupecki	wągrowiecki	Konin	grodziski
Zachodnio-pomorskie	Świnoujście	Szczecin	kamieński	pyrzycki	drawski	łobeski

Source: own research.

It is also worth noting the extreme values of the synthetic index in individual voivodeships (Table 4). The highest average value of the synthetic index was recorded in the counties of the Silesian Voivodeship, while the lowest was recorded in the counties of the Podlaskie Voivodeship. This can be explained by differences in economic structure, the degree of urbanization, environmental pressures, and the financial capacity of local governments. Above all, the Silesian Voivodeship is one of the most industrialized and urbanized regions in Poland. It has a high population concentration, developed heavy industry, and a dense network of technical infrastructure. Many years of industrial activity have resulted in numerous environmental problems, such as air pollution, soil degradation, and high greenhouse gas emissions. This necessitates the implementation of costly and advanced environmental investments, including those related to improving air quality, reclaiming brownfield sites, waste management, and modernizing energy systems. The high financial and institutional potential of the counties in the Silesian Voivodeship is also a significant factor. The Podlaskie Voivodeship, on the other hand, is characterized by a lower degree of urbanization and industrialization. It is a region dominated by agriculture and natural resources, with a large share of protected areas such as national parks and nature reserves. Environmental pressure is significantly lower there, limiting the need for large, costly technical investments. Considering the above, it can be concluded that the hypothesis posed in the introduction of this article has been positively verified.

Table 4.

Average, lowest and highest values of synthetic indicators by voivodeship along with the classification structure of counties

Voivodeship	synthetic indicator			Classification structure of counties			
	average value	minimum value	maximum value	I group	II group	III group	IV group
Dolnośląskie	0.205	0.121	0.260	13.3%	36.7%	40.0%	10.0%
Kujawsko-pomorskie	0.198	0.175	0.237	4.3%	30.4%	39.1%	26.1%
Lubelskie	0.201	0.176	0.239	8.3%	25.0%	41.7%	25.0%
Lubuskie	0.215	0.193	0.250	28.6%	35.7%	35.7%	0.0%
Łódzkie	0.201	0.182	0.221	0.0%	33.3%	50.0%	16.7%
Małopolskie	0.206	0.179	0.226	13.6%	27.3%	50.0%	9.1%
Mazowieckie	0.204	0.140	0.274	19.0%	28.6%	28.6%	23.8%
Opolskie	0.209	0.184	0.231	25.0%	41.7%	16.7%	16.7%
Podkarpackie	0.203	0.184	0.225	4.0%	36.0%	48.0%	12.0%
Podlaskie	0.196	0.176	0.252	5.9%	17.6%	35.3%	41.2%
Pomorskie	0.212	0.187	0.248	30.0%	30.0%	35.0%	5.0%
Śląskie	0.220	0.194	0.336	30.6%	41.7%	27.8%	0.0%
Świętokrzyskie	0.203	0.191	0.229	7.1%	28.6%	64.3%	0.0%
Warmińsko-mazurskie	0.205	0.186	0.255	14.3%	9.5%	71.4%	4.8%
Wielkopolskie	0.202	0.185	0.225	2.9%	28.6%	65.7%	2.9%
Zachodniopomorskie	0.208	0.192	0.239	4.8%	52.4%	42.9%	0.0%
Total	0.206	0.121	0.336	13.2%	31.6%	43.2%	12.1%

Source: own research.

Based on the data presented in Table 4, it can also be concluded that the Świętokrzyskie Voivodeship is the most homogeneous in terms of the scope of environmental investments, with the smallest difference between the maximum and minimum values of the synthetic indicator. In contrast, the greatest diversity in the scope of environmental investments was observed in the Silesian Voivodeship, where the leader in environmental investments (Racibórz County) is located, as well as in the Zawiercie and Lubliniec counties, where the scale of environmental investments is much smaller.

In the final stage of the study, the counties were classified based on the synthetic index value of each county relative to the mean value of the entire group (0.206) and the standard deviation (0.018). The results of this grouping are presented in Table 4 and Figure 2.

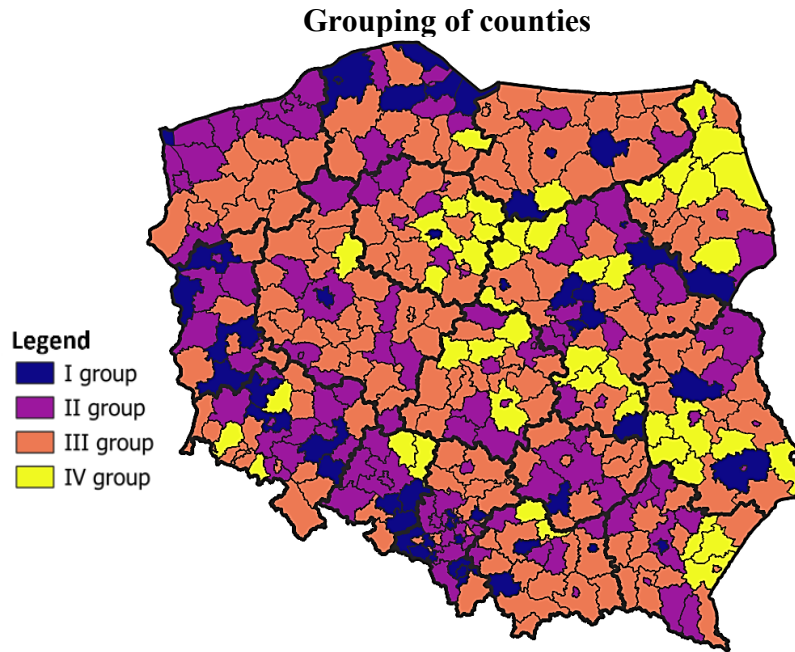


Figure 2. Grouping of counties based on the value of the synthetic index.

Source: own research.

Counties with the highest synthetic index values, classified as Groups I and II, are mostly located in southwestern, western, and northern Poland. These areas are characterized by a specific set of economic, historical, demographic, and environmental conditions that favor the implementation of extensive pro-ecological initiatives. Above all, these regions are among the most industrialized and urbanized parts of the country, where heavy industry, the energy sector, and transportation have been developing for decades. Long-term anthropogenic pressures have led to environmental degradation, necessitating comprehensive and costly investments in air protection, post-industrial land reclamation, waste management, and energy transformation. Historical and structural conditions are another factor. Western and northern Poland have a well-developed technical infrastructure, inherited and modernized from the post-war period, facilitating the implementation of modern environmental solutions. Natural and spatial factors are also significant. In northern Poland, investments related to marine and inland water protection, water and wastewater management, and adaptation to climate change, including flood protection and counteracting the effects of rising sea levels, are of significant importance. In the southwestern part of the country, investments related to protection against floods and the effects of mining activities are crucial.

In turn, the counties with the lowest synthetic index values, classified in group IV, are located primarily in central, northeastern, and southeastern Poland. These areas are characterized primarily by lower levels of urbanization and industrialization. Agricultural and natural functions dominate there, and anthropogenic pressure on the environment is significantly lower than in highly industrialized regions. Consequently, there is no urgent need for large-scale infrastructure investments, such as the reclamation of post-industrial areas or the modernization of advanced air protection systems. Another significant factor is the limited

financial capacity of local governments. These counties typically have smaller budgets resulting from lower revenues and a weaker tax base. This limits their ability to co-finance environmental projects, which often require significant own contributions. Another reason is the nature of the environmental activities undertaken. In northeastern and southeastern Poland, investments related to nature and landscape conservation predominate, including in national and landscape parks. These activities, while crucial for biodiversity conservation, typically do not generate significant financial outlays and are not considered large-scale infrastructure investments. Furthermore, the central part of the country has a dispersed settlement structure, which limits the profitability of large-scale infrastructure investments, such as extensive public transport systems or heating networks.

5. Discussion and Conclusions

The analysis of environmental investments in Poland indicates that they constitute a significant element of national development policy and a key tool for achieving environmental protection goals and the transition towards a low-emission economy. The scale and structure of investment activities confirm the growing importance of environmental issues in decision-making processes at both the national, regional, and local levels. At the same time, these investments demonstrate a clear connection to the legal and financial conditions resulting from Poland's membership in the European Union.

The positive verification of the hypothesis that highly industrialized counties dominate the structure of environmental investments confirms the existence of an ecological modernization mechanism in Poland, driven by the structure of the economy. The high ranking of units such as Płock County (refining industry), Polkowice County (mining industry), and Racibórz County (machinery and energy industry) indicates a direct relationship between endogenous economic potential and the propensity to incur pro-ecological expenditures. These results are consistent with the findings of Piontek (2020), who argued that in regions with high industrial concentration, environmental investments are a priority due to the need to mitigate negative externalities and stringent emission standards imposed by EU law.

The identified advantage of industrialized leaders over regions with a low degree of urbanization (the so-called "eastern wall" or agricultural regions) can be interpreted through the lens of economic base theory. Counties with a strong industrial base have higher revenues and a more stable tax base (property taxes, corporate income tax), which constitutes a necessary contribution to obtaining structural funds. As noted by Rosik et al. (2015), regions with high economic potential demonstrate higher institutional efficiency in absorbing earmarked funds. In this context, the lower scope of investment in less industrialized counties does not necessarily

result from a lack of need, but rather from a financial gap and a lack of economies of scale, which confirms the phenomenon of spatial polarization described by Churski et al. (2021).

It's also worth relating the obtained results to the concept of the Environmental Kuznets Curve. The fact that the wealthiest and most industrialized counties are implementing the greatest volume of investments suggests that these units have already passed a critical point where further economic growth must be integrated with the preservation of natural resources. This phenomenon, described in the international literature by Grossman and Krueger (1995), at the local scale in Poland takes the form of "ecological efficiency" clusters, where industrial capital paradoxically becomes the main financier of environmental improvements.

Based on the conducted analysis, several key conclusions can be drawn. First, environmental investments in Poland rely heavily on external financing sources, particularly EU funds, which favors the implementation of costly infrastructure projects, primarily by counties with strong economic potential, but also increases dependence on the fluctuating EU financial framework. Second, despite visible progress in the development of environmental protection infrastructure and renewable energy sources, the pace of investment implementation remains insufficient in the context of ambitious climate and environmental goals, especially in less industrialized regions. Third, institutional and procedural barriers remain a significant challenge, including the complexity of administrative processes and limited coordination between levels of public administration.

In light of the above conclusions, the following recommendations are justified. First and foremost, it is necessary to further strengthen national financing mechanisms for environmental investments to reduce excessive dependence on external funds and ensure greater sustainability of implemented projects. Furthermore, simplifying and streamlining administrative procedures is recommended, which could shorten investment implementation times and increase their efficiency. Intensifying activities supporting innovative technological solutions and developing the institutional competencies of entities responsible for implementing environmental projects is also crucial. Finally, it is essential to increase the coherence of sectoral policies and strengthen the role of long-term planning, which will allow for more effective targeting of environmental investments in Poland over the coming decades.

A significant aspect of analyzing environmental investments in Poland is their distinct spatial differentiation, visible at the level of individual counties. The scale and structure of implemented projects are largely determined by local socio-economic conditions, the level of technical infrastructure development, the availability of financial resources, and the institutional potential of local government units. As a result, significant disparities are observed between counties with high absorption capacity for investment funds and units struggling with financial and staffing constraints.

Counties with a higher level of economic development and greater experience in obtaining external funds, including European Union funds, are typically characterized by a higher intensity of environmental investments, especially in areas such as water and sewage

management, renewable energy sources, and improving energy efficiency. In peripheral and less developed counties, however, these investments are often localized and limited, which can lead to the perpetuation of spatial inequalities in environmental quality and access to modern infrastructure.

In light of the above observations, it is recommended to more closely consider the territorial dimension in the design and implementation of investment policies in the area of environmental protection. In line with the place-based approach promoted in the European Union's cohesion policy, it is reasonable to differentiate support instruments depending on the specificity and needs of individual counties. Particular attention should be paid to units with limited institutional potential by increasing the availability of advisory support, simplifying application procedures, and providing preferential financing conditions for environmental investments.

This study adds value to the literature by applying a multi-criteria approach (20 indicators) at a microregional (district) scale in the post-pandemic period. It demonstrates that the traditional approach to cohesion policy should better consider the specificity of industrial clusters as drivers of green transformation, while simultaneously strengthening support mechanisms for regions with lower income potential to prevent the phenomenon of "ecological exclusion". Although the analysis of 20 indicators provides a broad picture, future research should be expanded to include qualitative analysis (e.g., energy efficiency of achieved tangible effects) and incorporate flows of funds from the National Recovery Plan, which will allow for the assessment of the resilience of local environmental systems to external shocks.

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