European Research Studies Journal
Volume XXVII, Issue 3, 2024

pp. 950-961

Eco-Innovation and Sustainable Development: Comparing Regional Trends in Poland and the EU

Submitted 07/07/24, 1st revision 09/08/24, 2nd revision 26/08/24, accepted 30/09/24

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Abstract:

Purpose: *This study aims to examine the role of eco-innovation in promoting sustainable development across Poland's regions, with a comparative perspective on Poland's performance relative to other EU countries. The research seeks to highlight regional disparities in eco-innovation potential and assess the factors influencing sustainable development within the EU framework.*
Design/Methodology/Approach: *The study employs a mixed-method approach, integrating quantitative analysis of eco-innovation indicators from the Eco-Innovation Scoreboard and Millennium Eco Index. The data were gathered from the European Commission and Polish statistical sources to analyze trends and disparities across Poland's 16 voivodeships, comparing these findings with broader EU data.*
Findings: *Significant regional disparities in eco-innovation potential were observed within Poland, with Pomorskie, Małopolskie, and Mazowieckie leading, while Świętokrzyskie and Opolskie lag behind. Overall, Poland remains in the lower tier of EU nations, reflecting structural challenges and resource allocation issues. Targeted investments and policies could bridge these gaps, aligning Poland more closely with EU sustainability goals.*
Practical Implications: *The findings highlight the need for tailored regional policies in Poland that prioritize eco-innovation and sustainable practices, especially in underperforming areas. Stronger collaboration among government, industry, and communities is crucial to creating an inclusive framework that benefits the entire country.*
Originality/Value: *This study provides a comparative analysis of eco-innovation disparities within a single EU country, highlighting regional challenges and opportunities.*

Keywords: *Eco-innovation, Sustainable development, Regional disparities, Environmental policy, European Union, Poland, Technological innovation.*

JEL Codes: *Q01, Q55, O33, R11.*

Paper Type: *Research article.*

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1. Introduction

Sustainable development, also known as balanced, integrated, or eco-development (Żylicz, 1998), and more generally referred to as sustainability (Pawłowski, 2011), represents an economic approach that advocates maintaining the quality of life at a level consistent with the current state of civilisation, as opposed to Malthus' "iron law of economics."

The principle of sustainability is articulated in the initial statement of the WCED (1987), which posits that "at the present stage of civilisation, sustainable development is achievable, i.e., a development model in which the needs of the current generation are met without diminishing the capacity of future generations to meet their own needs."

The attainment of sustainable development objectives is supported through the application of innovation, particularly eco-innovation. Within the context of sustainable development, innovation is regarded as an instrumental value, serving as a mechanism for establishing improved conditions for living, employment, recreation, and various forms of human activity, while also safeguarding the natural environment.

The principal objective of this study is to highlight the role of eco-innovative activities in balancing Poland's socio-economic development relative to other EU countries. The specific aims, which contribute to achieving this principal objective, include: (1) conducting a review of international literature on the theoretical and practical dimensions of eco-innovation, focusing on its influence on balanced development; (2) undertaking an analysis of rankings based on selected indicators to demonstrate the level and trends in eco-innovation within Poland compared to other EU nations, along with an examination of regional disparities in eco-innovation activities across the 16 Polish voivodeships.

The completion of these objectives is intended to enhance the understanding of the mechanisms underlying the formation of eco-innovative activities within EU countries, with a specific emphasis on Poland, and to provide a basis for shaping current and future policies aimed at enhancing the sustainability of development in the EU by supporting eco-innovative efforts.

2. Literature Review

The EU has long emphasized sustainable development within its programming and policy documents, positioning it as a crucial goal for socio-economic balance. While the term "sustainable development" is widely recognized, its interpretation varies across sectors, often influenced by evolving environmental and economic contexts. The concept and framework of sustainable development in EU policy address current environmental challenges – such as climate change, pollution, resource

depletion, and biodiversity loss – which underscore the urgency of adopting sustainable practices to avert potential ecological crises and achieve long-term resilience (Cristea *et al.,* 2022; Forbes, 2024).

Increasing public awareness and regulatory measures further pressure both governmental and private sectors to integrate sustainable practices actively, underscoring a shared responsibility in maintaining ecological integrity across EU member states.

Eco-innovation, originally defined by Fussler and James, focuses on new products and processes that benefit both businesses and the environment (Karakaya, Hidalgo, and Nuur, 2014). Similar perspectives are shared by Kemp and Arundel (1998), Oltra and Saint Jean (2009), and Kemp and Pearson (2007). The European Commission expanded this concept to encompass a wide range of innovations – across production, services, and management – that advance sustainable development by reducing environmental impacts or enhancing resource efficiency (EC, 2007; EC, 2008).

The importance of eco-innovation is further underscored by the OECD (2009), which describes it as the development of products, processes, or organizational practices that offer measurable environmental benefits over traditional methods. Social approval is essential for successful eco-innovation, integrating it into the broader framework of sustainable development and emphasizing public involvement as a catalyst for effective change (Olejniczak, 2015; Tundys, 2015).

Eco-innovation encompasses several distinct types, including product, process, organizational, and marketing innovations. Product-based eco-innovations involve developing goods with reduced environmental footprints, such as using sustainable materials or enhancing energy efficiency. Process-based eco-innovations improve production methodologies to minimize waste and pollution, while organizational eco-innovations involve systemic changes, such as adopting environmental management systems (e.g., ISO 14000 series).

Marketing eco-innovations use “green marketing” approaches that appeal to eco-conscious consumers. These categories collectively advance circular economy models by promoting resource efficiency and waste reduction, essential elements of the European Union's strategy for achieving a sustainable future (World Bank, 2020; Rosiek, 2023).

Eco-innovation and sustainable business practices have also been recognized by a significant portion of business leaders, who acknowledge the need for sustainability integration into the product lifecycle; however, few have taken substantial action to implement these practices effectively (Plastech, 2022). According to the Financial Times, more than half of the surveyed executives recognize the importance of embedding sustainability within product development.

However, only 36% have concrete plans to actualize these commitments, indicating a disconnect between intentions and practical applications. Barriers include high costs, limited consumer demand, and a lack of cross-departmental prioritization within organizations. Additional challenges arise from insufficiently defined sustainability goals within corporate structures and limited technical expertise to drive these initiatives.

These barriers reveal a significant gap between sustainability awareness and practical implementation, impacting the speed at which sustainable innovations are adopted (Lipnik and Cergol Lipnik, 2020; Plastech, 2022). Financial motivations also play a key role, as companies require robust incentives to support optimization processes that align with sustainable practices (Małecka, 2023).

Open innovation as a catalyst for eco-innovation promotes collaboration and the free exchange of ideas among market and research stakeholders, gaining prominence as a means to accelerate eco-innovation. This approach involves the active participation of external partners – such as customers, suppliers, competitors, universities, and research institutions – thereby enhancing the collective knowledge pool.

Advances in artificial intelligence and digital tools have further enabled open innovation, facilitating feedback loops that integrate insights from consumers and the broader community. By fostering a more inclusive innovation ecosystem, open innovation aligns closely with sustainable principles and reinforces eco-innovation as a shared responsibility (Forbes, 2024).

Eco-innovation's role in sustainable development goals directly supports sustainable development by fostering technological, organizational, and behavioral changes that mitigate environmental impacts. As a critical driver of economic growth, innovation has long been associated with competitiveness and job creation, as posited by Schumpeter (1960) and later substantiated by studies examining economic transformation (Poskrobko, 2013).

Eco-innovation specifically supports sustainable development by addressing environmental concerns across product, process, and management levels. By aligning corporate strategies with eco-innovation objectives, companies contribute to the EU's sustainability goals, notably in reducing pollution, conserving resources, and achieving greater efficiency in energy and materials use (Chrząścik, Marciniuk-Kluska, and Kluska, 2010).

Technology and eco-innovation for future sustainability play a pivotal role in light of the increasing demand for sustainable solutions, as sectors such as energy, transportation, and data management are shifting toward more intelligent and efficient infrastructures. The integration of artificial intelligence, Power over Ethernet, and renewable energy sources reduces emissions, optimizes resource utilization, and supports sustainable economic transitions.

For example, smart grid technologies and digital energy management systems improve the efficiency of power distribution, while electric vehicle networks represent a transformative shift in sustainable transportation (Marszycki, 2024). These advancements underscore the role of eco-innovation as a dynamic contributor to sustainability and illustrate how technological progress aligns with the broader objectives of circular economy and climate resilience.

Eco-innovation, embedded within the EU's sustainability policy framework, is a critical tool for addressing contemporary environmental challenges. By promoting collaborative and innovative approaches across industries, eco-innovation aligns with the broader agenda of achieving sustainable development.

Evolving technological and organizational strategies that enable responsible resource management and environmental stewardship are essential for realizing a sustainable future. The integration of eco-innovation within business and government practices not only supports environmental goals but also contributes to social and economic resilience, driving a holistic approach to sustainability that is both adaptable and impactful.

3. Research Methodology

Available scientific studies on eco-innovation and sustainable development were analyzed, with a particular focus on the influence of eco-innovative activities in achieving a balanced approach to development. In addition to strictly scientific sources, key strategic documents from the European Union were reviewed, outlining the objectives and tasks for achieving balanced socio-economic development among member states, with eco-innovation identified as a crucial determinant. Notably, attention was directed towards documents prepared by the European Commission.

The empirical section presents findings on eco-innovation measurement based on:

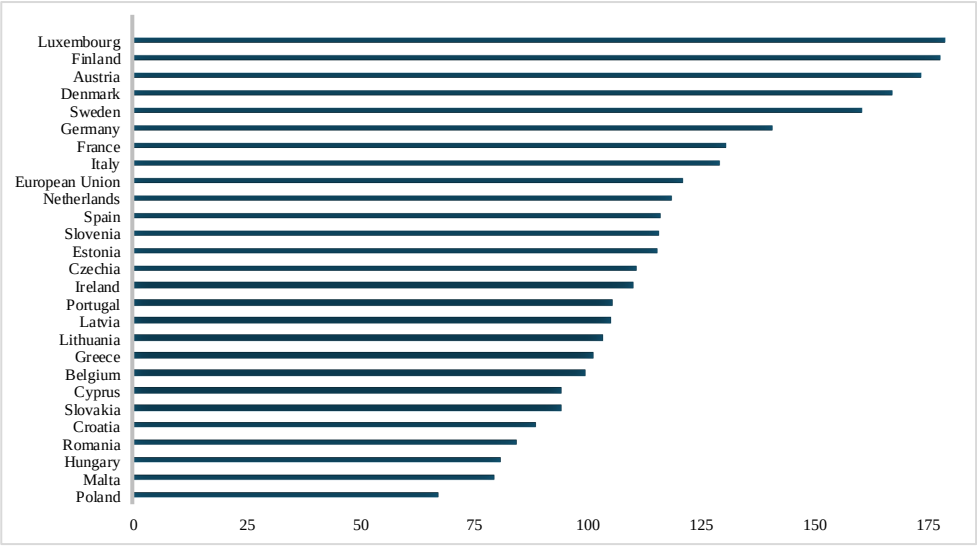
- an analysis of the Eco-Innovation Scoreboard index, developed by the European Commission (EC), illustrating the progression and dynamics of eco-innovation activities across European Union countries from 2013 to 2022,
- studies conducted by the authors of the Eco-Innovation Scoreboard, utilizing the Millennium Eco-Innovation Index for Polish voivodeships.

Data for this analysis were sourced from the Main Statistical Office (MSO)/Główny Urząd Statystyczny (GUS) and the Local Data Bank (LDB)/Bank Danych Lokalnych (BDL). The combination of these two analytical approaches enabled the integration of key theoretical insights with a rigorous empirical assessment of the examined issues.

4. Research Results

At the national level (EU-27), the Eco-Innovation Scoreboard serves as one of the most critical indicators for assessing the level and dynamics of eco-innovation development across European Union countries. It provides a comparative view of eco-innovation activities within different EU nations, highlighting variations in performance across member states (Figure 1).

Figure 1. *European Eco-innovation scoreboard 2022*



Source: *Own elaboration basd on eurostat data and green-business.ec.europa.eu/eco-innovation_en.*

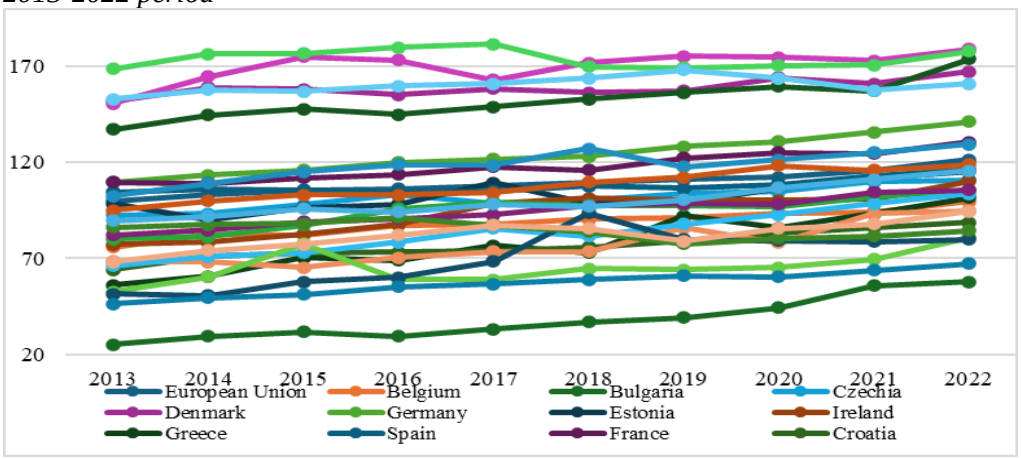
For benchmarking the eco-innovation potential of Polish regions (voivodeships) at the regional level, the Millennium 2023 Eco Index is applied. This index comprises 16 variables as stimulants of eco-innovation and one variable (carbon dioxide emissions to GDP) as a destimulant, incorporating the directional influence of each stimulant and destimulant in its calculations (Millennium Bank, 2022).

Analysis reveals significant variations in eco-innovation indicators (Eco-Innovation Scoreboard 2022 and Millennium Eco-Index 2022) across both national and regional levels. The 2022 Eco-Innovation Scoreboard positions Poland within the third, lowest-ranked group among EU countries, categorized as "catching-up" countries, where it ranks fourth after Belgium, Hungary, and Slovakia. Leading nations in eco-innovation, such as Germany, Finland, and France, consistently achieve high scores (Figure 1).

A historical analysis of eco-innovation trends from 2013 to 2022 shows Luxembourg, Finland, Sweden, and Denmark maintaining high and stable positions,

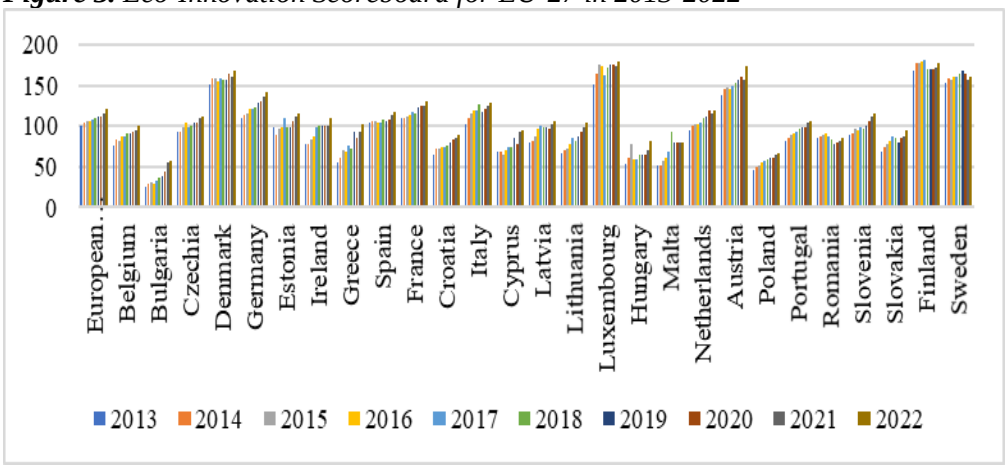
while Poland ranks near the bottom, just above Bulgaria. However, an upward trend is noted in Poland's index value, reflecting gradual improvement over the period (Figures 2 and 3).

Figure 2. *Eco-Innovation performance of EU members in selected indicatior in 2013-2022 period*



Source: *Own elaboration basd on eurostat data and green-business.ec.europa.eu/eco-innovation_en.*

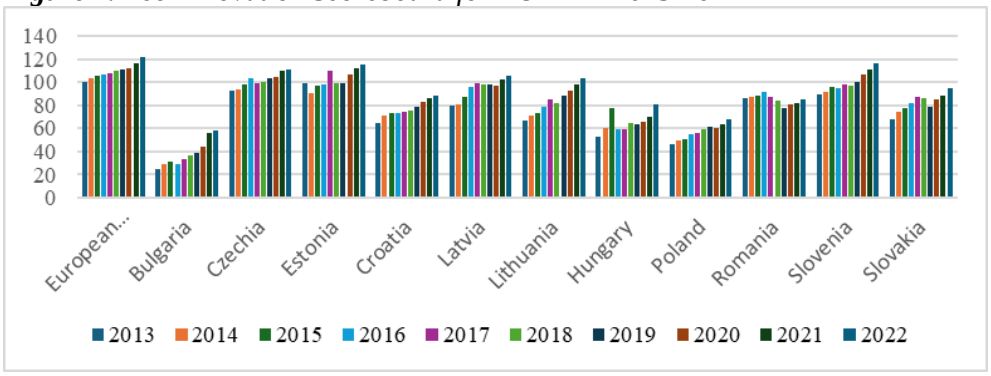
Figure 3. *Eco-Innovation Scoreboard for EU-27 in 2013-2022*



Source: *Own elaboration basd on eurostat data and green-business.ec.europa.eu/eco-innovation_en.*

The Eco-Innovation Index for the "new" EU countries (those joining in 2004 or later) further illustrates eco-innovation progress among Central and Eastern European countries and the Baltic States. Within this group, Czechia, Estonia, Latvia, and Slovenia lead, while Poland is positioned second-last, ahead only of Bulgaria, with each country scoring below the EU average (Figure 4).

Figure 4. *Eco-Innovation Scoreboard for EU-11 in 2013-2022*



Source: *Own elaboration basd on eurostat data and green-business.ec.europa.eu/eco-innovation_en.*

A regional analysis of eco-innovation diversity within Poland also underscores disparities across voivodeships. The Millennium 2022 Eco-Index and its sub-indices reveal that Pomorskie (68), Małopolskie (64), and Mazowieckie (61) achieve the highest composite index values, while Lubelskie (36), Opolskie (29), and Świętokrzyskie (25) have the lowest scores. The broad range of values, from 25 to 68, highlights substantial regional differences in eco-innovation activities within Poland (Table 1).

Table 1. *The Millennium Eco-Index in particular voivodeships in Poland in 2022*

Voivodeship	**ECO-innovation**			**Resource efficiency**	**Millennium 2022 Eco-Index**
	Inputs	**Effects**	**Socio-economic activity**		
Dolnośląskie	71	31	43	74	**51**
Kujawsko-Pomorskie	15	39	56	58	**41**
Lubelskie	38	20	35	62	**36**
Lubuskie	22	38	28	73	**37**
Łódzkie	46	48	41	48	**45**
Małopolskie	80	48	62	72	**64**
Mazowieckie	69	33	76	69	**61**
Opolskie	24	29	40	15	**29**
Podkarpackie	55	42	34	75	**49**
Podlaskie	25	38	44	82	**44**
Pomorskie	54	64	71	86	**68**
Śląskie	45	29	50	66	**46**
Świętokrzyskie	28	29	21	24	**25**
Warmińsko-Mazurskie	21	35	53	85	**46**
Wielkopolskie	35	40	43	71	**45**
Zachodniopomorskie	30	29	46	48	**38**

Note: *Commentary to Table 1. For the purposes of the survey carried out, all variables have been standardised, with the result that each of them takes values ranging from 0 (the*

province with the lowest reading of a given variable in a given year) to 100 (the leader in a given variable in a given year) in the individual years covered by the analysis. For each group of data, a sub-index was calculated, which is the arithmetic mean of the standardised variables included in a given category (each of them has equal weight in the sub-index). The overall Millennium Eco-Index summary is the arithmetic mean of all seven-teen variables included in the index, keeping their weights equal.
Source: *Millennium Bank, 2022.*

Diversity in Millennium Eco-Index results among Poland's voivodeships shows substantial variation in eco-innovation potential. Regions like Pomorskie, Małopolskie, and Mazowieckie rank highest, suggesting strong foundations and readiness for sustainable implementation. In contrast, the lowest values in Świętokrzyskie and Opolskie highlight a need for more investment in eco-friendly technologies and socio-economic support.

5. Discusion

The discussion of results reveals considerable disparities in eco-innovation levels both between EU countries and within Polish regions. Analysis of the Eco-Innovation Scoreboard (2022) data indicates Poland remains within the lower tier among EU nations, identified as part of the "catching-up" group.

Despite recent improvements, Poland’s ranking still lags behind the EU leaders in eco-innovation, who maintain high scores due to stable investment and policy support for sustainable development (Figure 1). This gap underscores the need for Poland to strengthen its eco-innovation infrastructure, increasing the support mechanisms that enable both public and private sectors to prioritize sustainable practices.

Poland's regional analysis offers additional insights, with voivodeships such as Pomorskie, Małopolskie, and Mazowieckie demonstrating significant eco-innovation potential. High values for the Eco-Innovation inputs sub-index, recorded in Małopolskie (80), Dolnośląskie (71), and Mazowieckie (69), reflect strong foundations for eco-innovation activities in these regions.

Additionally, Pomorskie shows substantial eco-innovation effects, with a high sub-index score of 64. Socio-economic activity in eco-innovation is most robust in Mazowieckie (76) and Pomorskie (71), underscoring the socio-economic support for eco-innovation within these regions (Table 1). These areas showcase a model for integrating innovation with local socio-economic conditions, demonstrating the potential of regionalized approaches to drive eco-innovation.

Resource efficiency, a critical component of eco-innovation, achieves the highest sub-index values in Pomorskie (86), Warmińsko-mazurskie (85), and Podlaskie (82). For all 16 Polish voivodeships, this sub-index score remains relatively higher than

other sub-indices, indicating a consistent emphasis on resource management across Polish regions.

However, the overall disparity in eco-innovation scores between the top- and bottom-ranking voivodeships highlights areas for improvement, particularly in regions with lower eco-innovation scores, as Poland strives to align more closely with EU sustainability goals. Targeted investments and policy initiatives focusing on underperforming regions could help mitigate these differences, ensuring a more balanced and sustainable national eco-innovation landscape.

The discussion also highlights that Poland's position in the "catching-up" group of EU countries reflects structural challenges, such as limited funding and uneven distribution of eco-innovation resources, which restrict eco-innovation advancements.

Addressing these challenges requires a strategic policy focus on enhancing regional innovation ecosystems, particularly in voivodeships with lower scores like Świętokrzyskie and Opolskie. Developing partnerships between public and private sectors, academia, and local communities could bolster eco-innovation capacities, ensuring that knowledge and resources are more effectively disseminated across regions.

Furthermore, the socio-economic support evident in higher-ranking regions suggests that aligning eco-innovation initiatives with local development goals is essential. Tailored incentives for eco-friendly technologies and regional innovation hubs may stimulate greater engagement and participation in eco-innovation activities, particularly in underserved areas. This approach not only supports Poland's national sustainability objectives but also aligns with broader EU goals, potentially raising Poland's profile within the EU eco-innovation landscape and fostering more inclusive economic and environmental benefits across all regions.

6. Limitations of the Study

This study has several limitations: (1) Data Aggregation: indices like the Eco-Innovation Scoreboard may overlook regional specifics, (2) Focus Scope: emphasis on environmental and economic factors neglects social aspects like community engagement, (3) Comparative Issues: data inconsistencies affect cross-country rankings, (4) Temporal Scope: recent data may not capture long-term trends or policy impacts, (5) Indicator Bias: certain metrics may skew results, favoring specific regions or approaches. These limitations underline the need for comprehensive research to better understand eco-innovation drivers.

7. Conclusions

The findings underscore that while Poland is gradually advancing in eco-innovation,

it remains behind leading EU countries, highlighting the need for enhanced support for sustainable practices across its regions. Significant regional disparities in eco-innovation performance point to a need for a targeted, multi-faceted approach that prioritizes tailored support, especially for underperforming areas like Świętokrzyskie and Opolskie, which would benefit from increased investments in eco-friendly technologies and socio-economic resources.

High-ranking regions such as Pomorskie and Małopolskie demonstrate how robust eco-innovation infrastructure can foster regional leadership in sustainable practices, providing a model that could be adapted in other regions to drive balanced growth.

Efforts to enhance Poland's eco-innovation potential could be strengthened by fostering collaboration between public institutions, private enterprises, and local communities, enhancing knowledge transfer and resource sharing critical to sustainable growth. As global environmental standards continue to evolve, it will also become vital for Poland to align its eco-innovation initiatives with EU and international sustainability frameworks, thereby enhancing its competitiveness and ensuring resilience.

Given the limitations of current data aggregation methods, which may obscure finer regional nuances, further research is essential. Incorporating qualitative insights and a broader range of indicators will enable a more comprehensive understanding of Poland's eco-innovation landscape and allow for more precise, adaptable policy measures.

In pursuing a cohesive national strategy that integrates economic, environmental, and social dimensions, Poland can achieve a more sustainable trajectory that supports both local and EU-wide sustainability objectives, fostering inclusive, long-term growth across all regions.

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