ENVIRONMENTAL REGULATION AND GREEN INNOVATION: EVIDENCE FROM WESTERN AND CENTRAL AND EASTERN EUROPEAN COUNTRIES

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Abstract

The paper examines differences in eco-innovation performance and environmental policy frameworks between Western European Union (EU) and Central and Eastern European (CEE) countries over the period 2011–2022. Using a descriptive and comparative approach, the study analyzes multiple dimensions of eco-innovation, including a composite eco-innovation index, innovation inputs, activities, outputs, and resource-efficiency outcomes. Environmental regulation is captured through the Environmental Policy Stringency (EPS) index and an indicator of market-based environmental policy instruments. The analysis combines level comparisons, dispersion measures, compound annual growth rates (CAGR), graphical trends, and correlation analysis.

The results reveal persistent structural heterogeneity between regions. Western EU countries consistently exhibit higher levels of eco-innovation, environmental policy stringency, GDP per capita, and R&D intensity. In contrast, CEE countries start from substantially lower levels but display faster long-term growth in several eco-innovation indicators, indicating partial catch-up dynamics. However, convergence remains incomplete, as substantial absolute gaps and high volatility persist. Policy trends show divergence rather than convergence, with regulatory stringency increasing in Western EU countries while stagnating or declining in CEE countries. Correlation analysis further highlights regional differences: environmental policy indicators are positively associated with eco-innovation in Western EU countries, but show weak or negative associations in CEE economies. Overall, the findings underline the importance of institutional and structural context in shaping the regulation–innovation nexus and suggest that environmental regulation supports eco-innovation in heterogeneous ways across European regions.

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1. Introduction

Recent strategic EU policy initiatives, including the Draghi Report and the EU Competitiveness Compass, emphasize that Europe's long-term competitiveness must be strengthened through innovation-led growth and the scaling of clean technologies into manufacturing leadership. Central to this agenda is the need to revive Europe's innovation cycle while aligning decarbonization with competitiveness, industrial policy, and economic security. In this context, environmental regulation is increasingly viewed not only as a tool for reducing environmental externalities but also as a potential driver of innovation, industrial upgrading, and the diffusion of clean technologies.

Eco-innovation occupies a pivotal position within this policy framework. It is explicitly embedded in Sustainable Development Goal 9 and contributes more broadly to the achievement of multiple sustainability objectives by providing technological and organizational solutions to environmental challenges. Owing to its cross-cutting character, fostering eco-innovation has become a core priority of European Union policy at multiple governance levels (Hajdukiewicz & Pera, 2023). Nevertheless, firms often perceive environmental regulation as a source of coercive pressure, encouraging only minimal compliance-driven innovation, in line with traditional neoclassical arguments (Lah & Kotnik, 2026). In contrast, theoretical foundations of the Porter Hypothesis suggests that well-designed and sufficiently stringent environmental regulation can stimulate innovation and potentially offset compliance costs by enhancing efficiency and competitiveness (Cai & Li, 2018; Porter & Van der Linde, 1995).

Despite extensive policy efforts, substantial differences persist across EU member states. Western EU countries generally exhibit stronger innovation systems, higher R&D intensity, and leading positions in international competitiveness rankings (Pece et al., 2015). By contrast, Central and Eastern European (CEE) countries continue to lag behind, facing structural constraints such as lock-in effects related to pollution-intensive technologies and limited absorptive capacity, which may hinder the development and diffusion of eco-innovation (Vávra et al., 2021). Moreover, these countries tend to be characterized by a greater reliance on pollution-intensive production, lower levels of R&D expenditure, and lower environmental awareness among citizens, whereas regulatory activity appears to play a comparatively more important role in stimulating adoption of eco-innovation within that group of countries (Horbach, 2016). Existing empirical evidence suggests that the innovation gap between eco-innovation leaders and catching-up economies has not substantially narrowed over time (Hajdukiewicz & Pera, 2023). In line with this perspective, Petrariu et al. (2013), using a panel data approach, demonstrate a strong link between economic development and innovation, showing that the level of an economy's development, particularly reflected in resource allocation to R&D, is a key determinant of innovation performance.

Against this background, this paper provides a descriptive and comparative analysis of eco-innovation performance and environmental policy frameworks across selected Western EU and CEE countries over the period 2011–2022. Focusing on multiple eco-innovation indicators and measures of environmental policy stringency, the study examines differences in levels, long-term growth trends, and dispersion across regions. It also includes correlation analysis across the indicators of environmental policy stringency and eco-innovation activity. By documenting stylized facts on regional heterogeneity, the paper contributes to a better understanding of how eco-innovation performance and environmental regulation evolve across different institutional contexts and provides important context for subsequent causal analyses.

2. Literature Review

2.1 Eco-Innovation: Concept and Drivers

Eco-innovation has emerged as a distinct extension of traditional innovation theory by explicitly incorporating environmental considerations into economic and organizational change. The concept was

originally introduced by Fussler and James (James & Fussler, 1996) and broadly refers to the development of new products and processes that reduce environmental impacts while simultaneously creating value for firms and consumers (Hajdukiewicz & Pera, 2023; Yurdakul & Kazan, 2020). A widely cited definition describes eco-innovation as the production, application, or exploitation of goods, services, processes, organizational structures, or business methods that are novel to the firm or user and that, over their life cycle, reduce environmental risks, pollution, and the negative effects of resource and energy use relative to relevant alternatives (Kemp & Foxon, 2007). This environmental dimension differentiates eco-innovation from Schumpeter's classical notion of innovation, which emphasizes novelty without explicitly addressing environmental performance (Yurdakul & Kazan, 2020).

The literature on eco-innovation can broadly be divided into studies examining its drivers, its outcomes, or both. Research focusing on drivers often draws on innovation theory and resource-based perspectives, emphasizing technology-push and demand-pull mechanisms, internal firm capabilities, and institutional conditions shaping innovation incentives (Hojnik & Ruzzier, 2016). From an outcome perspective, eco-innovation is closely linked to improvements in eco-efficiency, defined as the ability to reduce the use of environmental resources per unit of output while maintaining or enhancing economic value (Figge & Hahn, 2012). Accordingly, eco-innovation is frequently viewed as a key mechanism for achieving sustainable economic development by simultaneously reducing environmental pressures and supporting economic and social performance (Hojnik & Ruzzier, 2016; Hajdukiewicz & Pera, 2023). Some studies integrate both perspectives, showing that internal capabilities and external pressures jointly determine eco-innovation and its economic and environmental outcomes (Cai & Li, 2017).

2.2 Environmental Regulation and Eco-Innovation

A substantial body of literature highlights the role of institutional and regulatory pressures, particularly environmental regulation, in shaping eco-innovation activities (e.g. Luo et al., 2021; Ramanathan et al., 2017; Rubashkina et al., 2015). Government regulation can be regarded among central mechanisms for limiting environmentally harmful economic behavior and encouraging firms to adopt cleaner technologies and practices (Hojnik & Ruzzier, 2016). Environmental policy frameworks typically combine market-based instruments, such as emissions trading schemes, environmental taxes, feed-in tariffs, and deposit-refund systems, with non-market instruments, including environmental standards and public R&D subsidies. Overall regulatory stringency is often captured by composite indicators such as the OECD's Environmental Policy Stringency (EPS) index.

The relationship between environmental regulation and innovation is commonly framed through the Porter Hypothesis, which challenges the traditional neoclassical view of regulation as a pure cost burden. The weak version of the hypothesis argues that stricter environmental regulation stimulates certain types of innovation, while the narrow version emphasizes that flexible, market-based instruments are particularly conducive to innovation and productivity gains (Franco & Marin, 2017; Xie et al., 2017). Although Porter and Van der Linde's original argument was cautiously formulated, subsequent empirical research suggests that well-designed environmental regulation can indeed promote firms' internal research efforts and innovation activities by strengthening incentives to develop cleaner and more efficient technologies (Arthur et al., 2023).

Despite this growing body of evidence, the literature also points to considerable heterogeneity in regulatory impacts, shaped by differences in institutional quality, innovation capacity, and economic development. These differences are particularly relevant within the European Union, where Western and Central and Eastern European countries exhibit distinct innovation systems and policy environments. This heterogeneity motivates comparative analyses that focus on descriptive patterns, long-term trends, and convergence dynamics in eco-innovation performance across regions.

Building on the conceptual and empirical literature reviewed above, and given the persistent heterogeneity between Western and Central and Eastern European countries, the following research questions were formed:

RQ1: What are the most recent trends in eco-innovation performance in selected Western EU countries compared to CEE countries, and has the innovation gap narrowed over the observed period?

RQ2: How do environmental policy stringency and the use of market-based environmental instruments differ between Western EU and CEE countries, and has convergence occurred over time?

RQ3: Is there a correlation between environmental policy stringency and eco-innovation indicators?

3. Methodology and Data

This study employs a comparative descriptive approach to examine differences in eco-innovation performance and environmental policy frameworks between Western EU and Central and Eastern European (CEE) countries. The analysis covers the period 2011–2022, subject to data availability, and focuses on identifying long-term patterns, growth dynamics, and regional heterogeneity rather than causal effects.

3.1. Data and Indicators

Eco-innovation performance is measured using a set of indicators derived primarily from the Eco-Innovation Index, including a composite index as well as sub-dimensions, i.e. eco-innovation inputs, activities, outputs, and resource-efficiency outcomes. Environmental regulation is proxied by the Environmental Policy Stringency (EPS) index from OECD and by an indicator capturing the intensity of market-based environmental policy instruments, such as environmental taxes and emissions trading schemes. In general, EPS consists of two components, market-based and non market-based instruments (Albrizio et al., 2017). The indicator ranges from 0 to 6, with higher values indicating more stringent environmental policies, and its advantage lies in simplifying a complex set of multi-dimensional policies into a comparable country-specific proxy. In practice, the credibility of the EPS as a proxy for a country's overall environmental policy stringency is validated by comparing it with other available measures of environmental policy stringency (Albrizio et al., 2017). EPS index has been particularly relevant also for its use in the Porter Hypothesis testing as it directly measures the stringency of environmental policy. Studies (e.g. Martínez-Zarzoso et al., 2019; Rubashkina et al., 2015) have used it in cross country research among OECD countries to test different versions of the Porter Hypothesis on the macro level. However, Cecere & Corrocher (2016) argue that environmental stringency indexes, though promising, require extensive data and may misclassify countries as stringent simply for joining international treaties without ensuring compliance.

To allow regional comparison, countries are grouped into Western EU and CEE categories based on historical, institutional, and economic characteristics commonly used in the literature. Additional control indicators, including GDP per capita (PPP) and R&D expenditure, are used to provide contextual interpretation of observed patterns.

3.2. Analytical Approach

The analysis proceeds in four steps. First, descriptive statistics (means, standard deviations, minimums, and maximums) are computed to assess differences in levels and dispersion of eco-innovation indicators across regions. Second, compound annual growth rates (CAGR) are calculated to capture long-term growth dynamics and convergence trends between Western EU and CEE countries. Third, graphical

comparisons are used to illustrate regional trajectories and highlight differences in volatility and structural development. Fourth, a descriptive correlation analysis is conducted to examine simple associations between environmental policy indicators and selected eco-innovation measures. This step provides preliminary insight into whether policy and innovation outcomes move together differently across regions, without implying causality. This descriptive framework allows for the identification of stylized facts regarding eco-innovation performance and environmental regulation across heterogeneous European regions.

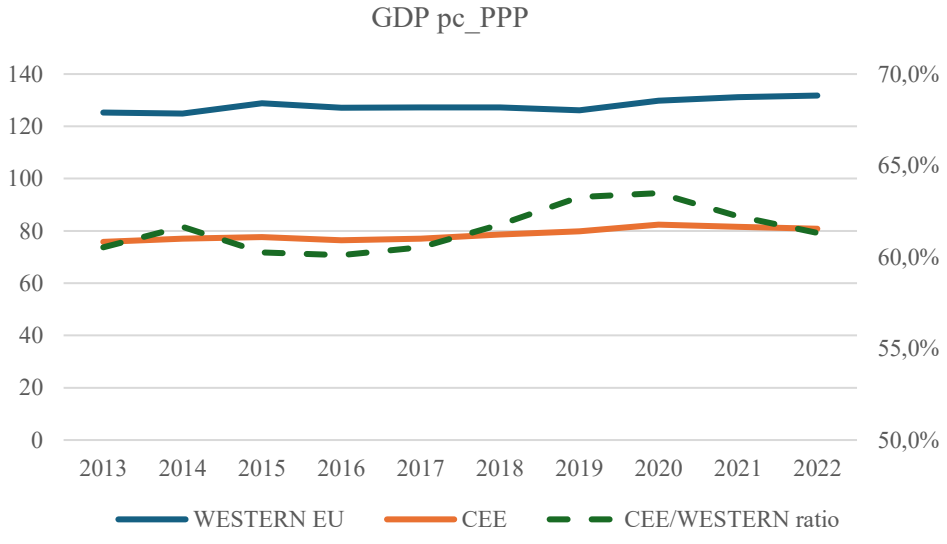
4. Results

4.1. GDP pc PPP and R&D expenditures in Western EU and CEE countries

Figures 1 and 2 present trends in GDP per capita (PPP) and R&D expenditure for Western EU and CEE countries over the period 2013–2022, providing important context for the subsequent analysis of eco-innovation performance and environmental policy frameworks. Western EU countries consistently exhibit substantially higher levels of GDP pc PPP and R&D intensity throughout the observed period. GDP per capita in CEE countries remains at approximately 60–63% of the Western EU level, indicating only modest convergence over time. A similar pattern emerges for R&D expenditure: although CEE countries show gradual improvement, their R&D intensity reaches only around 55–60% of the Western EU average, with a particularly noticeable dip in the mid-2010s.

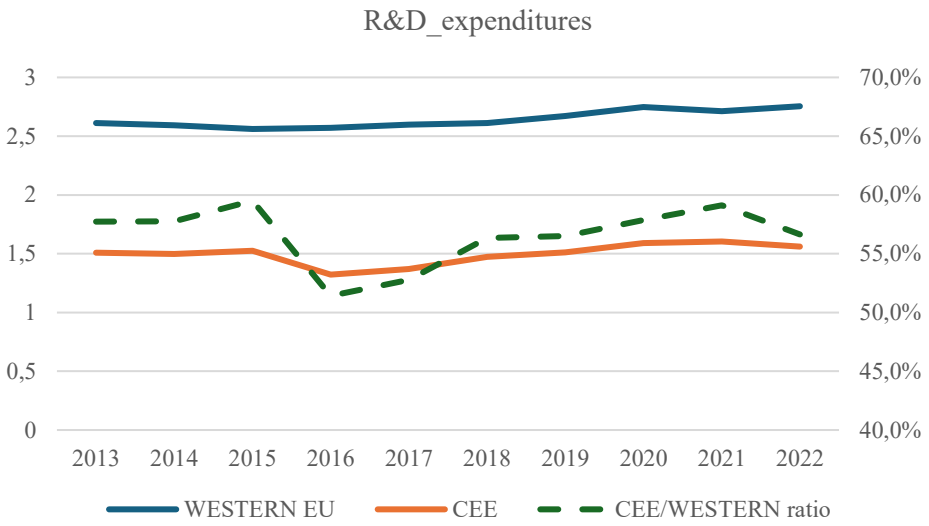
Importantly, both indicators display considerable stability in relative terms, suggesting that structural differences in economic development and innovation capacity persist despite overall growth in CEE economies. These enduring gaps in income and R&D investment help explain the observed heterogeneity in eco-innovation outcomes and the weaker alignment between environmental policy and innovation in CEE countries. Consequently, differences in GDP per capita and R&D intensity provide a crucial backdrop for interpreting regional disparities in eco-innovation performance and the divergent responsiveness to environmental regulation identified in subsequent sections.

Figure 1: GDP per Capita in PPP in Western EU and CEE Countries and the CEE-to-Western Ratio, 2013–2022



Source: Own elaboration based on Eurostat data

Figure 2: R&D expenditures in Western EU and CEE Countries and the CEE-to-Western Ratio, 2013–2022



Source: Own elaboration based on Eurostat data

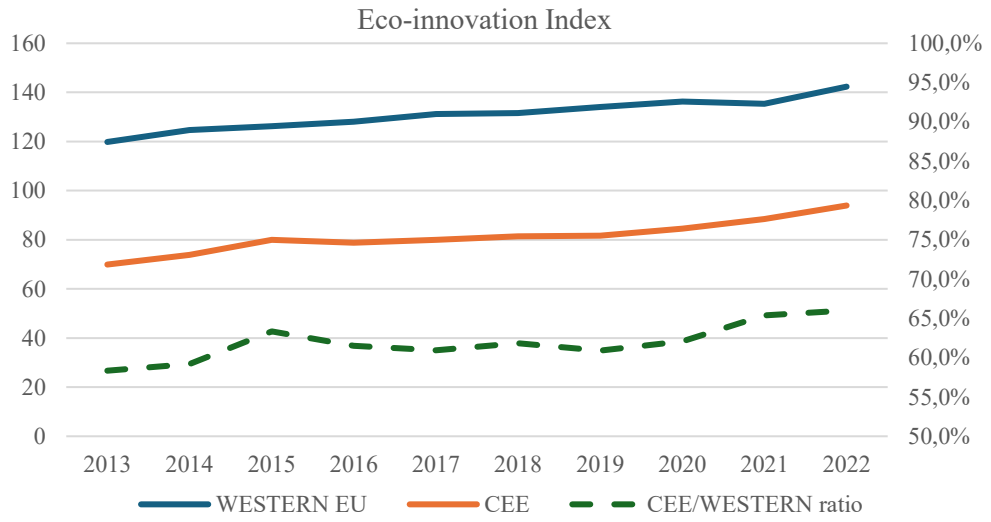
4.2. Eco-innovation performance in Western EU and CEE countries

The descriptive analysis reveals substantial and persistent differences in eco-innovation performance between Western European Union (EU) countries and Central and Eastern European (CEE) countries as depicted in Figure 3. Across all observed years, Western EU countries consistently exhibit higher average levels of eco-innovation, measured by the composite Eco-Innovation Index. CEE countries, in contrast, start from significantly lower baseline levels across nearly all indicators of eco-innovation.

Despite these level differences, long-term growth dynamics indicate a more nuanced pattern. Compound annual growth rate (CAGR) analysis shows that CEE countries display systematically higher growth rates for several eco-innovation indicators, particularly eco-innovation inputs and outputs. However, this convergence remains incomplete, as substantial absolute gaps in eco-innovation levels persist over the observation period.

Notably, the analysis also highlights marked differences in volatility across regions. Eco-innovation activities in CEE countries exhibit significantly higher dispersion, with wide ranges and large standard deviations, indicating irregular and unstable innovation trajectories. Western EU countries, by contrast, show more stable and predictable patterns across all eco-innovation dimensions. These findings suggest that while CEE countries experience faster growth in some indicators, their innovation processes remain less structurally embedded and more sensitive to short-term fluctuations.

Figure 3: Eco-Innovation Index in Western EU and CEE Countries and the CEE-to-Western Ratio, 2013–2022



Source: Own elaboration based on Eurostat data

Table 1 highlights pronounced and persistent differences in eco-innovation performance between Western EU and CEE countries. Western EU countries consistently exhibit higher average levels across most eco-innovation indicators, reflecting more mature and deeply embedded innovation systems. The composite eco-innovation index in CEE countries reaches only about 62% of the Western EU level, and similar gaps are observed for eco-innovation inputs (58%) and outputs (39%). At the same time, dispersion is generally lower in Western EU countries, indicating more stable and predictable innovation performance, whereas CEE countries display higher volatility, particularly in innovation inputs and activities.

Despite these level differences, growth dynamics suggest partial convergence in several dimensions. CEE countries record higher compound annual growth rates for eco-innovation indicators, with growth differentials of 1.4 percentage points for the composite index, 2.0 p.p. for inputs, and 3.7 p.p. for outputs relative to Western EU countries. This indicates ongoing catch-up dynamics from a lower base. However, convergence remains incomplete, as absolute gaps in levels persist and volatility remains substantially higher in CEE countries. Resource-efficiency outcomes represent an exception, with identical long-run growth rates in both regions, suggesting that convergence may be more advanced in environmental performance than in innovation capacity itself. Overall, the results point to sustained structural heterogeneity, where faster growth in CEE economies coexists with enduring differences in levels and stability across eco-innovation indicators.

Variable	N	Mean	Std. Dev.	Min	Max	CAGR
Eco-innovation index (West)	90	130,95	30,55	75,91	181,55	1,9%
Eco-innovation index (CEE)	50	81,24	19,34	46,45	115,86	3,3%
Difference CEE / West ratio × 100		62%	63%	61%	64%	1,4%
Eco-innovation inputs (West)	90	122,52	35,59	54,15	179,14	1,1%
Eco-innovation inputs (CEE)	50	70,84	29,00	28,60	131,11	3,1%
Difference CEE / West ratio × 100		58%	81%	53%	73%	2,0%
Eco-innovation activities (West)	90	95,30	64,21	20,30	300,83	0,1%
Eco-innovation activities (CEE)	50	145,92	83,78	8,97	300,83	2,8%
Difference CEE / West ratio × 100		153%	130%	44%	100%	2,7%
Eco-innovation outputs (West)	90	153,04	46,91	93,03	240,20	1,3%
Eco-innovation outputs (CEE)	50	60,31	23,55	29,56	133,36	5,0%
Difference CEE / West ratio × 100		39%	50%	32%	56%	3,7%
Resource efficiency outputs (West)	90	123,99	40,09	17,34	206,81	4,1%
Resource efficiency outputs (CEE)	50	94,59	30,83	39,34	150,74	4,1%
Difference CEE / West ratio × 100		76%	77%	227%	73%	0,0%

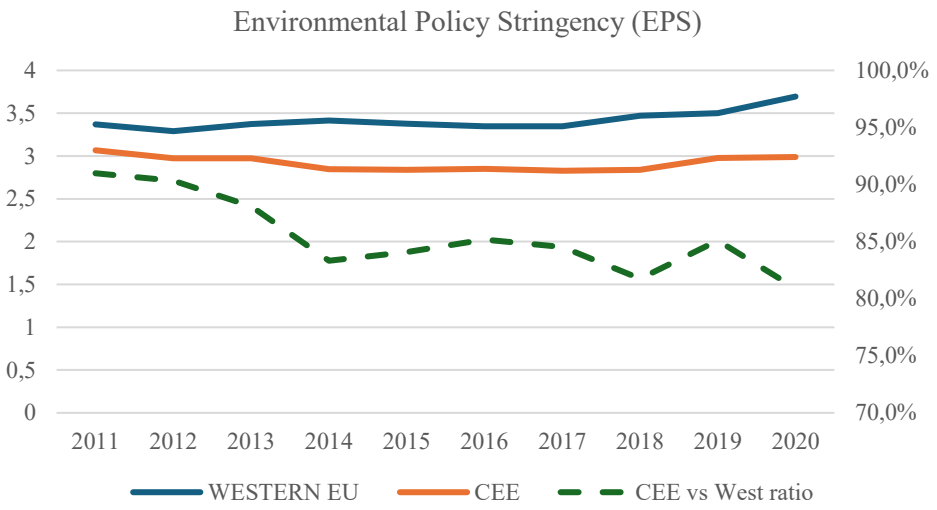
Source: Own elaboration based on Eurostat data

4.3. Environmental policy stringency and market-based instruments

Clear regional differences are also observed in the design and evolution of environmental policy frameworks. Western EU countries display higher average levels of environmental policy stringency, as captured by the Environmental Policy Stringency (EPS) index, alongside more extensive use of market-based environmental instruments. Moreover, policy frameworks in Western EU countries show a steadily increasing trend over the observed period, indicating consistent regulatory tightening.

CEE countries, in contrast, are characterized by lower average policy stringency and more limited reliance on market-based instruments. Long-term growth rates of these policy indicators in CEE countries are positive but modest, suggesting only partial convergence toward Western EU regulatory standards.

Figure 4: Environmental policy stringency in Western EU and CEE and the CEE-to-West Ratio, 2013–2022



Source: Own elaboration based on OECD data

Table 2 documents clear and persistent differences in environmental policy frameworks between Western EU and CEE countries. Western EU countries exhibit higher average environmental policy stringency, with a mean EPS value of 3.42, compared to 2.92 in CEE countries. In addition to higher levels, Western EU countries show greater dispersion in policy stringency, reflecting more differentiated and flexible regulatory regimes, with EPS values ranging from 2.44 to 4.89. By contrast, CEE countries display a narrower range of EPS values (2.42 to 3.67) and lower standard deviation, indicating more homogeneous but generally less stringent regulatory environments. A similar pattern emerges for market-based environmental instruments: although their average level in CEE countries (1.58) slightly exceeds that of Western EU countries (1.11), Western EU countries exhibit substantially greater variation and considerably higher maximum values, suggesting deeper and more diversified use of market-based instruments.

Table 1: Descriptive statistics of Environmental Policy Stringency by variables (Western EU and CEE Countries)

Variable	N	Mean	Std. Dev.	Min	Max	CAGR
EPS (West)	90	3,42	0,51	2,44	4,89	1,0%
EPS (CEE)	50	2,92	0,27	2,42	3,67	-0,3%
Difference CEE / Western EU ratio		0,85	0,53	0,99	0,75	-1,3 p.p.
Market based (West)	90	1,11	1,95	0,67	4,17	2,9%
Market based (CEE)	50	1,58	0,63	0,83	3,17	0,40%
Difference CEE / Western EU ratio		0,81	0,57	1,25	0,76	-2,5 p.p.

Source: Own elaboration based on OECD data

An examination of growth dynamics provides limited evidence of regulatory convergence. While Western EU countries record positive long-term growth in environmental policy stringency, with an EPS CAGR of +1.0%, CEE countries experience a slight decline in EPS over the same period (–0.3%). As a result, the CEE-to-Western EU EPS ratio declines over time, and the CAGR differential of –1.3

percentage points indicates divergence rather than convergence in overall regulatory stringency. A similar divergence is observed for market-based instruments: Western EU countries show a strong positive growth rate (+2.9% CAGR), whereas growth in CEE countries remains modest (+0.4% CAGR), leading to a CAGR differential of –2.5 percentage points. In sum, these results suggest that differences in environmental policy design and intensity across EU regions remain persistent and, in some respects, have widened over time. Such divergence in regulatory frameworks may contribute to the heterogeneous eco-innovation outcomes observed between Western EU and CEE countries in subsequent analyses.

Although comparison of average EPS levels between Western EU and CEE countries points to divergence rather than convergence, due to decline of EPS in CEE countries, this decline is largely driven by developments in Hungary, where EPS decreased markedly from 3.67 in 2011 to 2.81 in 2020. However, if Hungary is excluded from the sample, the average EPS in CEE countries would instead increase, from 2.92 in 2011 to 3.03 in 2020, suggesting that the observed divergence is strongly influenced by country-specific dynamics rather than a uniform regional trend.

4.4. Correlation between environmental policy stringency and eco-innovation

The correlation analysis provides additional insight into the heterogeneous relationship between environmental policy and eco-innovation across regions. In Western EU countries, both environmental policy stringency and market-based instruments are positively associated with eco-innovation performance, particularly with eco-innovation inputs, indicating that regulatory frameworks and innovation investments evolve together in mature innovation systems. In contrast, CEE countries display weak or negative correlations between policy indicators and eco-innovation outcomes. Environmental policy stringency shows virtually no association with innovation inputs, while market-based instruments are negatively correlated with the composite eco-innovation index. These patterns suggest that regulatory signals are not effectively transformed into innovation activity in CEE economies and may instead reflect structural constraints, institutional fragmentation, and limited absorptive capacity. Overall, the results are consistent with earlier descriptive findings showing faster growth but higher volatility in CEE countries and highlight the importance of institutional context in shaping the policy–innovation nexus.

Table 2: Correlation between Environmental Policy Stringency, Market-Based Instruments, and Eco-Innovation Indicators

Region	EPS ↔ Eco-Index	Market-based ↔ Eco-Index	EPS ↔ Inputs	Market-based ↔ Inputs
WESTERN EU	0.53 (moderate +)	0.47 (moderate +)	0.71 (strong +)	0.54 (moderate +)
CEE	–0.15 (weak −)	–0.52 (moderate −)	–0.01 (neutral)	–0.23 (weak −)

Source: Own elaboration based on Eurostat and OECD data

5. Conclusion

This paper examined differences in eco-innovation performance and environmental policy frameworks between Western European Union (EU) and Central and Eastern European (CEE) countries over the period 2011–2022, with a particular focus on long-term trends, convergence dynamics, and simple associations between regulation and innovation outcomes. By combining descriptive statistics, compound annual growth rates, and correlation analysis, the study provides stylized facts that contribute to the ongoing debate on the role of environmental regulation in fostering eco-innovation across various institutional contexts.

The results reveal significant differences between the two regional groups. Western EU countries consistently exhibit higher levels of eco-innovation across all dimensions, supported by higher GDP per capita and stronger R&D intensity. In contrast, CEE countries start from a substantially lower base but display faster long-term growth in several eco-innovation indicators, particularly in innovation inputs and outputs. These findings are in line with the eco-innovation literature emphasizing catch-up dynamics in less developed economies, yet they also underline that convergence remains incomplete, as large absolute gaps and significantly higher volatility persist in CEE countries (Hojnik & Ruzzier, 2016; Hajdukiewicz & Pera, 2023).

Beyond innovation performance, the analysis documents diverging trajectories in environmental policy frameworks. While environmental policy stringency and market-based instruments have intensified steadily in Western EU countries, CEE countries exhibit stagnation or even mild decline in overall policy stringency. This divergence contrasts with EU policy ambitions and suggests that regulatory convergence has been weaker than innovation catch-up. From an institutional perspective, these asymmetries help explain why regulatory pressure may be perceived differently across regions and why similar policy instruments do not generate uniform innovation responses.

The correlation analysis further highlights this heterogeneity. In Western EU countries, environmental policy indicators are positively associated with eco-innovation, particularly with innovation inputs, reflecting mature innovation systems in which regulation and innovation evolve in the same direction. In CEE countries, however, correlations are weak or negative, especially for market-based instruments and the composite eco-innovation index. This pattern resonates with the literature suggesting that in catching-up economies, institutional fragmentation, limited absorptive capacity, and structural lock-ins may impede the translation of regulatory signals into sustained innovation activity (Vávra et al., 2021; Horbach, 2016). At the same time, these findings are consistent with the cautious interpretation of the Porter Hypothesis, which emphasizes that regulatory benefits depend on design, flexibility, and institutional context rather than on stringency alone (Porter & Van der Linde, 1995; Cai & Li, 2017).

Overall, the results suggest that environmental regulation can support eco-innovation, but its effectiveness is highly context-dependent. While Western EU countries appear able to integrate regulatory pressure into stable innovation processes, CEE countries face persistent structural constraints that limit convergence despite favorable growth dynamics. These findings underscore the importance of region-specific policy design that combines environmental regulation with targeted support for innovation capacity, R&D investment, and institutional development. The descriptive evidence presented here provides a foundation for future research employing dynamic econometric methods to assess the causal mechanisms linking environmental regulation and eco-innovation across different stages of the innovation process.

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