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Economic and institutional determinants of environmental health and sustainability: Spatial and nonlinear effects for a panel of worldwide countries

JEL Classification: *C23; C33; Q56*

Keywords: *contagion and diffusion; spatial panel; threshold panel; environmental health; environmental performance; environmental sustainability*

Abstract

Research background: This study identifies the key factors influencing environmental health across a global panel of countries, focusing on protection from environmental hazards, as informed by the existing literature, while also shedding light on novel aspects of these causal relationships.
Purpose of the article: This study aims to reveal, through a comprehensive review of the relevant literature, the underexplored phenomena of spatial diffusion and contagion of national environmental behaviors and the nonlinear dynamics between environmental performance and its determinants, acknowledging the significant diversity in the characteristics and behaviors of the countries studied.
Methods: Spatial analysis and econometric methods, including spatial panel regression alongside dynamic panel models using threshold techniques, were employed to meet the study's objectives.
Findings & value added: This study's major finding is that environmental performance across nations shows significant clustering influenced by economic and institutional factors. This clustering effect arises from spatial contagion and diffusion processes, as evidenced by spatial panel regression analysis. Furthermore, this study demonstrates that variations in environmental behavior can be attributed to differing levels of development and specific internal conditions within countries. Notably, a country's gross domestic product and the proportion of industries in its economy have a substantial effect on its environmental health practices, establishing distinct impact thresholds. This research enriches academic dialogue by illustrating, through these thresholds, that in less developed countries, an increased industrial share leads to environmental degradation. Moreover, the influence of the other examined factors varied depending on the category of the country under review, highlighting the nuanced effects of economic and institutional variables on environmental outcomes.

Introduction

Economic and institutional determinants play an essential role in analyzing a country's environmental performance, especially in the context of intensifying globalization and economic interdependence (Wang *et al.*, 2020). Understanding the effects of environmental health (EH) determinants is decisive for good governance (Tatar *et al.*, 2024; Rahman & Alam, 2022), as it equips leaders with the knowledge to implement policies that protect public health and ensure equitable access to clean air, water, and soil. Effective natural resource management is integral to this process as it helps prevent the reduction of critical resources and mitigates the impact of environmental dangers on human health. By aligning with the sustainable development goals (Taghvaee *et al*., 2022; Bali Swain & Yang-Wallentin, 2020), studying these determinants encourages a holistic approach to tackling global challenges, promoting sustainability, and enhancing the well-being of communities worldwide. This knowledge supports public health initiatives by identifying and addressing the root causes of health disparities, leading to more resilient and healthy populations (Lenzen *et al*., 2020). Therefore, examining the effects of EH determinants is the key to fostering sustainable development and safeguarding the health of current and future generations.

Factors such as economic growth (Lazăr *et al*., 2019), income distribution (Liu *et al*., 2018) and industrial development (de Mello Santos *et al*., 2022) are acknowledged as substantial determinants of environmental performance, illustrating the complex interaction between human economic activities and ecological sustainability. The relationship between these factors and environmental outcomes is complicated, which introduces a degree of uncertainty in predicting the exact impact. Economic growth can intensify pressures on ecosystems through escalated consumption of resources and energy, reflecting a direct challenge to environmental sustainability. Conversely, such growth has the potential to catalyze technological innovations and structural economic shifts towards more sustainable practices, highlighting its dual-edged influence on EH. Institutional factors, including the spectrum of government policies, legislative frameworks, and the effectiveness of law enforcement, play a key role (Muhammad & Long, 2021; Nemeckova & Hayat, 2022) in shaping a nation's environmental footprint, notably influencing their carbon footprint (greenhouse gas emissions) and management of natural resources. Robust and efficient institutional systems are crucial for fostering sustainable development as they enable the implementation of environmental regulations and the monitoring of their impact on ecosystems. Lastly, global disparities in institutional quality lead to varied responses to environmental challenges, underscoring the importance of adapted approaches that consider the specific socioeconomic and legislative contexts of different regions.

Assessing the mechanisms of territorial diffusion and contagion in the context of environmental performance provides a critical understanding of how a nation's environmental policies and actions can exert influence across borders and affect regional and global ecological outcomes. Environmental diffusion primarily involves the transfer of technology and the adoption of green innovations among neighboring countries (Sun *et al*., 2021; Yi, 2023), which can significantly enhance environmental standards and practices. This process facilitates the widespread adoption of sustainable technologies, expediting the global transition towards environmentally friendly norms and practices. By contrast, contagion of environmental policies is driven by political decisions and regulatory frameworks that inspire neighboring states to implement comparable environmental strategies, potentially within the framework of formal unions or international associations (Dedeurwaerdere *et al*., 2016). Dynamic interchange, including the movement of people and the sway of public opinion, along with collective concerns about global environmental challenges, has pushed the spread of such policies. Successful environmental strategies can act as benchmarks, initiating a domino effect that encourages broader adoption of sustainable practices among nations. Additionally, significant environmental occurrences, such as natural disasters or climate crises, can catalyze a ripple effect, prompting neighboring countries to reconsider and strengthen their environmental policies. The heightened awareness and subsequent policy adjustments that follow such events underscore the interconnectedness of nations in addressing and mitigating environmental issues. Thus, understanding the processes of diffusion and contagion in environmental performance is essential for fostering a collaborative international approach to achieve sustainable development goals. For example, Liu and Wang (2024) showed that the environmental performance of Chinese firms is influenced by higher regulatory stringency. Shi (2022) also examined EH in China and provided recommendations for low- and middle-income countries.

This study empirically examined the spread and impact of EH policies and practices across borders through statistical analysis, highlighting the complex influence of socioeconomic and institutional factors on countries' environmental performance and advocates for adaptive policy responses. Overall, this study proves the existence of EH contagion and diffusion processes among neighboring countries, alongside the existence of a threshold in the relationship between environmental performance and its determinants.

The remainder of this paper is organized as follows. Section 2 presents a literature review of the most important concepts supporting the research objectives: theoretical and empirical studies on the socioeconomic and institutional determinants of EH, as well as theoretical arguments regarding the effects of behavioral mimetics that can lead to diffusion and contagion effects on environmental performance. The research goals were aligned with the proposed objectives and the theoretical support provided in the literature. Section 3 outlines our data sources and research methodology. The results are discussed in the following sections, including comparisons with previous studies to determine whether there are similar or contrasting findings. The paper ends with conclusions, including implications, limitations, and perspectives for future research.

Literature review

Both theoretical and empirical studies have focused intensively on highlighting the determinants of environmental performance. Macro-level studies investigate the economic, social, or institutional determinants of environmental quality at the national level, whereas micro-level studies assess human behavior and sociodemographic variables. Most research has concentrated on a specific set of factors (Liu & Wang, 2024), whereas others have attempted a more comprehensive approach (Velte, 2023; Yew *et al*., 2022). Nevertheless, there is a notable gap in the literature regarding the investigation of neighborhood relationships and the diffusion and contagion phenomena of environmentally and ecologically related behaviors.

Socio-economic determinants of environmental performance

Socioeconomic factors shape countries environmental performance significantly, with key determinants including economic development, income distribution, and industrial structure. The literature underscores the effect of economic development on environmental initiatives, with developed countries investing in cleaner technologies and sustainable practices (de Mello Santos *et al*., 2022). Cleaner production is highlighted as a strategic choice to reduce industrial environmental impacts (de Mello Santos *et al*., 2022). The relationship between economic growth and the environment is explored using the environmental Kuznets curve, which reveals a nonlinear pattern. Empirical studies, such as those on Central and Eastern European countries (Lazăr *et al*., 2019), offer nuanced insights into the complex dynamics between economic development and pollution. Income distribution is a crucial factor influencing environmental outcomes. Social and economic inequalities affect natural resource utilization, often affecting disadvantaged groups disproportionately. Liu *et al.* (2018) demonstrated that an appropriate level of income inequality could enhance environmental quality over time, with implications for CO2 emissions (Wang *et al*., 2023).

Economic and industrial structures affect environmental performance significantly. Transitioning to cleaner and more energy-efficient sectors, especially in industry and agriculture, can reduce environmental impacts (Dogan & Inglesi-Lotz, 2020). As a proxy for economic structure, the share of the industrial sector in the GDP challenges the environmental Kuznets curve hypothesis, revealing a U-shaped relationship (Dogan & Inglesi-Lotz, 2020; Germani *et al*., 2020). Mitigating the environmental impact of high industrial proportions involves the development of energy-efficient technologies (Cheng *et al*., 2021a; Yew *et al*. 2022). Investments in education and research and development (R&D) play pivotal roles in environmental quality. These factors drive technological innovation, resource efficiency, and environmental awareness. Clean technology development, influenced by R&D investments, contributes to reducing the environmental impact of human activities (Mikulčić *et al*., 2016; Sharma *et al*., 2023). Education and R&D also affect resource use efficiency, with knowledge of sustainable natural resource management reducing excessive consumption and waste (Liu *et al*., 2022). Supporting education and R&D fosters better environmental performance through awareness and environmental education, particularly among educated individuals who are more likely to adopt sustainable behaviors (Varela-Candamio *et al*., 2018). The adaptability of the economy to environmental challenges is enhanced through R&D expenses. Investments in climate-resistant crops, infrastructure adaptation technologies, and natural resource management programs have contributed to resilience (Srivastav *et al*., 2021). Kopnina (2020) critiques the Education for Sustainable Development Goals' alignment with the growth paradigm, highlighting how it exacerbates inequalities and environmental degradation and advocates alternative ecocentric education models. Understanding causal relationships is even more important as the environment and ecology are increasingly connected to many aspects of the current economy and society: responsible consumption (Hosta & Zabkar, 2021; Lubowiecki-Vikuk *et al*., 2021), ecological activism (Wallis & Loy, 2021), education and awareness (Manolis & Manoli, 2021), and ecological tourism and sports (Haibo *et al*., 2020; Ciocan & Milon, 2017; McCullough *et al*., 2020).

The relationships between economic growth, income distribution, industry composition, educational influences, and investments in R&D significantly affect a nation's environmental performance. This analysis offers a detailed understanding of the complex variables involved and underscores the multifaceted nature of the factors that influence environmental outcomes.

Institutional determinants of environmental performance

Environmental issues differ from conventional market dynamics, often necessitating the intervention of public authorities. A country's institutional quality, which encompasses stability and dimensions such as the rule of law, is essential for shaping effective and sustainable environmental policies (Muhammad & Long, 2021; Nemeckova & Hayat, 2022). Robust public institutions with clear objectives foster compliance with environmental laws and prudent natural resource management (Yan & Haroon, 2023; Ahmad *et al*., 2021). Corruption poses a significant hurdle, negatively affecting resource management and environmental protection efforts (Wang *et al*., 2020). The control of corruption, which is indicative of institutional effectiveness, influences governance, with effective governance allowing swift responses to environmental challenges and efficient resource allocation (Tan *et al*., 2023).

Citizen participation in framing environmental objectives and policies is crucial in counteracting autocratic systems, enhancing supervision, and encouraging protective measures (Mello Rose *et al*., 2022). The long-term stability of environmental policies is imperative for effectiveness.

Wang *et al.* (2021) demonstrated that political stability and the consistent execution of public policies play a crucial role in ensuring the longevity of environmental initiatives. Howes *et al.* (2017) emphasized the importance of governance efficiency in the effective allocation and management of financial resources for environmental policies and the success of conservation efforts. Conversely, they noted that the effectiveness of policy implementation is often compromised by economic and political challenges, which pose obstacles to global environmental sustainability initiatives. Therefore, robust governance and high-quality institutional frameworks are essential to foster an environment conducive to environmental protection and the development of sustainable strategies (Brodny & Tutak, 2023). These elements can be measured using specific indicators that provide valuable insight into a nation's environmental performance and identify potential areas for improvement or targeted interventions. This approach highlights the significant impact of governance and institutional quality on environmental outcomes.

Diffusion and contagion effects in environmental performance

Beyond economic and institutional factors, the diffusion and contagion of environmental policies among geographical neighbors are influenced by mimetic behavior. Technological diffusion is a key channel involving the transfer and adoption of green technologies and sustainable practices (Halleck-Vega *et al*., 2018). Collaboration, partnerships, and exchanges facilitate knowledge transfer, encouraging neighboring states to adopt effective environmental solutions (Sun *et al*., 2021; Yi, 2023). The success of one country stimulates interest in other countries, creating competition and pressure to align with high environmental standards (Dedeurwaerdere *et al*., 2016). Collaboration within formal frameworks, like state unions such as the EU, enhances the accessibility and attractiveness of ecological technologies (Grybaitė *et al*., 2022; Bartolome *et al*., 2022). The diffusion of innovative environmental technologies can be contagious and accelerate the global transition to sustainable norms and practices (Clark, 2022).

Environmental policies also exhibit diffusion and contagion effects among neighbors through political decisions, regulations, the movement of people, public pressure, international opinion, global concerns, and chain reactions. Innovative policies serve as models for neighboring states, with state unions, such as the EU, playing a significant role in diffusing policies (Knill & Liefferink, 2021). Increased global awareness has resulted in successful environmental policies attracting international attention and influencing the adoption of appropriate regulations. On a broader scale, international opinion exerts pressure on the adoption of best practices and influences states to follow suit (McGregor *et al*., 2020). Participation in international agreements and treaties regulates policy diffusion globally, creating chain reactions and accelerating the global transition to ecological practices (Downie, 2022; Yilmaz & Koyuncu, 2023; Chersan *et al*., 2023). Responses to environmental challenges further contribute to territorial diffusion and contagion among neighbors. Common experiences during natural disasters, shared awareness, and collaboration have led to the spread of environmental priorities and actions among neighboring countries (Kusano & Kemmelmeier, 2018). The relationship among technological diffusion, policy contagion, and responses to challenges underscores the importance of regional collaboration and awareness in achieving a global ecological transition.

As previously outlined, neighboring countries exhibit behavioral mimicry in environmental matters through three primary channels: the spread of technology, the contagion of environmental policies, and responses to environmental challenges. Despite discussions and debates in the academic literature, empirical studies employing spatial methodologies to validate these phenomena are noticeably absent. The literature presents discrepancies regarding the influences of specific economic factors on environmental performance. These inconsistencies are believed to have arisen from the use of imperfect instruments. Our objective is to offer further insight into these mechanisms by utilizing dynamic panel data econometrics that incorporate threshold effects. This approach aimed to address and clarify the existing gaps in our understanding of these complex interactions.

Spatial and dynamic threshold panel econometrics were used to address the weaknesses of the methodological approaches found in the literature. Most of the literature focuses on the environmental Kuznets curve (Lazăr *et al*., 2019; de Mello Santos *et al*., 2022, etc.) and points out different shapes such as the U-shape (Dogan & Inglesi-Lotz, 2020; Germani *et al*., 2020) and N-shape, among others. However, none of these studies considered neighboring effects and environmental disasters that go beyond national boundaries and lead to spatial processes. In addition, countries behave differently depending on their economic, cultural, and social characteristics, leading to the need for a threshold assessment.

Research methods

Data

Data from 166 countries across all continents from 2010 to 2022 were used for the analyses. Because the environmental variable (EH) values were available only in even years within this interval, the data for the other variables were collected similarly. For some countries, the data are incomplete; therefore, the number of observations is reported in each regression. The data were exclusively sourced from internationally reputable databases: World Bank (2023), World Bank–WGI (2023), and the Environmental Protection Index (Yale University, 2023). The variables in the descriptive statistics and regression analyses are presented in Table 1 and include abbreviated names, explanations, and a few descriptive statistics.

These variables were selected based on the literature. EH is proxied using different variables. CO_2 emissions are used by Lazăr *et al.* (2019), whereas Sharma *et al.* (2023) use other environmental parameters. This study used the EH index, as it is more complex and encompasses all environmental aspects that are important for this research. The same path was used to select the determinants. Further, GDP (Lazăr *et al*., 2019; Dogan & Inglesi-Lotz, 2020) and education (Mikulčić *et al*., 2016; Sharma *et al*., 2023; Varela-Candamio *et al*., 2018) complete the variable panel, as most of the assessed studies identify these two aspects as main determinants for environmental performance. The rule of law and institutional quality were identified by Nemeckova and Hayat (2022) and Tan *et al*. (2023), among others.

Method

As the goal of the analysis is to account for spatial effects in the relationship between environmental performance and factors originating from economic or institutional groups, spatial statistics and econometric techniques are employed. The first step was to assess the spatial distribution of the variables and observe whether any spatial processes occurred worldwide. Different types of map were used for this purpose. As the sample comprises most countries in the world, there is high heterogeneity in the data. Therefore, the variables are centered in the median.

Another important step in the analysis is to cluster the sample of countries based on the variables considered and, once again, assess whether there are spatial patterns in the clustering process. The most efficient clustering methodology is k-means clustering. The averages for the variables are provided; based on these, the clustering procedure and between- and within-cluster sums of squares are conducted. As the work is on panel data, clustering analysis may be conducted for each year or the entire period being analyzed. This article presents the results for the clusters obtained based on the averages for the entire period for the environmental performance proxy, EH, and the variables that turned out to be the most impactful proxies for development, education, or institutions.

The data are regular in time, allowing for the application of panel estimation methods. As the main interest is in the spatial processes that manifest worldwide in terms of environmental performance, the spatial panel was the first to start with. However, to account for the spatial effects, a neighboring scheme given by the spatial weights matrix (W) was constructed. An assessment of worldwide data indicates that islands are present in the population. Consequently, a distance-based spatial weight matrix that allows islands to have neighbors (allows island countries to interact with the rest of the population) must be used. Again, heterogeneity was observed in the analyses. To address this, several matrices (based on distances with distance thresholds or in the k-nearest neighbor form) were constructed and tested for appropriateness. Among these, the most efficient was the inverse distance matrix, which was normalized in spectral form. The spatial weights matrix was employed in the computation of the spatial lag of the variable: the average value of the neighbors of each spatial unit, as given by the matrix, computed as the product of the vector of the variables values and the spatial weights matrix.

In terms of econometric modelling, the research starts from the assumption that there are significant spatial effects in all types of components of the estimated model — the dependent variable, factors, and errors– meaning that we have spatial autoregressiveness in the dependent variable (spatial lag), factors (Durbin effects), and errors (spatial moving average processes, requiring spatial error correction). This is the general nesting spatial model (GNS), and is given by equation (1):

$$\begin{gathered} Y = \rho WY + X\beta + WX\theta + \varepsilon \\ \varepsilon = \lambda W\varepsilon + u \end{gathered} \tag{1}$$

where:

WY	the spatial lag of the dependent variable;
WX	the spatial lag of the factor/ factors;
$W\varepsilon$	the spatial lag of the errors that corrects the moving average processes present in the model and accounts for spatial dependencies coming from other variables than the ones included in the estimation process;
ρ	the coefficient of WY;
θ	the coefficient of the spatial lags of the factors;
λ	the coefficient of the spatial lag of the errors;
u	the final error of the estimation process, which has the same properties as the errors in classical estimation methods.

The components were tested for significance and the final form of equation (1) is presented in the Results section. If the coefficients of the spatial lags are significant, the assumptions are validated, and there are significant spatial effects on the interaction between the considered factors and the level of environmental protection. Moreover, the total effects can be divided into direct and indirect effects.

The heterogeneity of behaviors with respect to both environmental protection and factors has already been emphasized. Threshold panel estimations are also used to account for this. The level of development may result in significantly different types of behaviors. Therefore, tests for the presence of thresholds given by GDP and the share of industry in the national economy were conducted. The tested models are given by equation (2), with the threshold variables being *GDP_CAP* or *IND_GDP*.

$$EH_{it} = \mu_i + \alpha_0 + \tag{2}$$
$$+\begin{cases} \alpha_{\_b} EH_{it-1} + \theta + \sum \beta_{\_bk} X_{itk} + \varepsilon_{it}\,, & if(TRESHOLD\_VARIABLE_{it} \leq \theta \\ \alpha_{\_a} EH_{it-1} + \theta + \sum \beta_{\_ak} X_{itk} + \varepsilon_{it}, & if(TRESHOLD\_VARIABLE_{it} > \theta \end{cases}$$

where:

- μ_i the country-specific fixed effect treated by orthogonal transformation;
- a_0 regime-dependent intercept;
- *_b* below the threshold denotes the coefficients obtained for the below-threshold situation;
- *_a*, above the threshold denotes the coefficients obtained for the above threshold situation;
- α the coefficient of the lag of EH, which accounts for the autocorrelation in the dependent variable; it assesses the inertial behavior of EH in time;
- θ the threshold value given by the threshold variable, either *GDP_CAP* or *IND_GDP*;
- β the coefficients of the factors, below or above the threshold;
- ε the panel errors, which is i.i.d.

If the assumption of heterogeneous behavior in terms of environmental protection conditioned by the development level and share of industry in the national economy is true, a significant potential threshold effect should be found on the one hand and differences in the effect of the considered determinants on EH should be found on the other.

All estimates underwent the necessary post-estimation validation procedures. Analyses were performed using Tableau 2023.3, STATA 16, and GeoDa 1.2.

Results

Descriptive analyses based on maps indicate that spatial processes are manifested in terms of environmental protection worldwide. Maps of EH are presented from three perspectives: in 2010, the beginning of the analyzed period; in 2022, the end; and the average for the entire period (see Figures 1 and 2).

Comparing Figures 1 and 2, it can be observed that the majority of countries with values below the median for *EH* are in Africa and Asia, with Europe, Australia, and the Americas positioned above the median score. Additionally, the environmental performance of most countries remained stable over time, with very few exceptions. Nordic European countries were the most efficient in terms of environmental protection throughout the entire analysis period. Classical European clustering in the West–East direction is also found in environmental protection behavior. We also observed a North–South cluster in the Americas, with North America performing better than South America. The clear clusters emphasized by the descriptive analysis based on maps also leads to the hypothesis that there are significant contagion and diffusion processes taking place, as neighboring countries seem to have similar behavior in terms of environmental protection. This was tested using a spatial panel regression, as described in the methodological section.

African countries experienced the highest environmental performance problems throughout the study period. The situation also worsened in India and its neighbors. Consequently, spatial effects manifest in this respect, at least in the first descriptive assessment. Moreover, the maps in Figures 1 and 2 indicate that these clusters and spatial effects are conditioned by the level of development, with poorer countries having lower *EH* scores.

Following the results shown in Figures 1 and 2, cluster analysis was chosen to assess the clustering process in a simple manner. The starting point was the dependent variable *EH* (Figure 3), followed by the main economic and institutional factors employed in the threshold panel analysis

(Figure 4). These clusters were constructed using the average values in the period analyzed. It is important to note that the cluster analysis pointed out the efficiency of grouping the countries into four clusters in each of the two situations — with or without determinants. For the simple clusters based on EH (Figure 3), a between-group variance of 11.92 and a within-group variance of 0.72 were obtained. When introducing economic and institutional factors, the BSS was 31.7 and the WSS was 16.67. The post-cluster evaluation confirmed the validity and stability of the results.

For EH alone, Cluster 1 comprises the most developed countries in the world (36), such as Northern European countries, Western European countries, Greece, Japan, Australia, New Zealand, Canada, and the United States of America. According to the cluster characterization based on descriptive statistics, these countries have the highest average *EH* scores (86.37), indicating that they are the most environmentally friendly. Cluster 2 has 54 countries that ranked second in terms of environmental performance, with an average *EH* score of 65.6. It is made up of most Eastern European countries, except Greece, the Czech Republic, Slovakia (which are in the 1st cluster), Russia, most South American countries, Tunisia, Jordan, Saudi Arabia, the United Arab Emirates, Malaysia, and South Korea, among others. Cluster 3 comprises some of the poorest countries in the sample, which are located in Africa and South Asia (India and neighboring countries). These countries (43) had the lowest environmental performance, with an average *EH* score for the entire period of only 28.74, being less than half that of Cluster 1. The last cluster comprises 31 countries that are either poor or developing countries: states from Central America such as Guatemala, Honduras, Nicaragua, South America; African countries like Egypt and Morocco in the north or South Africa and Namibia in the south. The majority of the countries in this cluster are from Asia (China, Mongolia, Indonesia, etc.). They rank 3rd in terms of environmental performance, with an average *EH* of 48.69, closer to Cluster 2 (that ranks 2nd) than to Cluster 3 (the lowest performing).

The introduction of the main factors in the clustering process did not alter Clusters 1 and 2 much, but led to significant changes in Clusters 3 and 4 (see Figure 4). There are interchanges between them: many African countries leave Cluster 3, the lowest performing, and join Cluster 4; whereas some Middle Eastern and Asian countries move from Cluster 4 to Cluster 3. Cluster 1 (33 countries) had, on average, the highest environmental performance (86.38), highest GDP per capita (47851 USD), and the best quality of institutions and politics (1.43 for government effectiveness and 1.42 for rule of law). It has the lowest share of industries in the national economy, with an average of 25.76%. Education expenditure ranks second in terms of GDP, with an average of 13.26 for the period analyzed.

For example, China and Egypt are now in the 2nd cluster, along with Eastern Europe, Turkey, Russia, the Middle East, and parts of South America (such as Brazil). There were 48 countries in this cluster. Their average *EH* score was 66.5, and the average GDP per capita was 11691 USD. They also ranked 2nd based on institutional quality, with positive scores of 0.12 for government effectiveness and 0.05 for rule of law. There was very little difference between Clusters 1 and 2 in terms of the share of industry in the GDP (12.3%) and education expenditure (12.3%).

Cluster 4 comes in 3rd, comprising 53 members, mostly from Africa, Asia, and South America. The only European countries are Moldavia, Bosnia, and Herzegovina. Their average EH is now further from Cluster 2 and closer to that of the lowest performing cluster, Cluster 3. These countries ranked 3rd in respect to GDP per capita, industrial importance in the national economy, and institutional quality. However, they spent the most on education, which was quite different from other clusters (18.37 %).

The worst environmental performance was observed in Cluster 3, which had 30 members. The mean *EH* was 32.78. These countries had the lowest GDP, worst institutions, and spent the least on education. However, they had the highest share of GDP obtained from industrial activities.

Descriptions of these clusters based on average values are presented in Table 2.

Visual and descriptive analyses based on maps and clusters revealed two important spatial patterns: (1) clustering of environmental performance behavior in space, with very clear spatial characteristics that emphasize similar behaviors among neighboring countries, and (2) contagion and diffusion processes. All of these seem to be conditioned by the development level and institutional quality. Thus, we conducted a spatial panel regression to test the validity of these descriptive findings. In academic literature, there are further concerns regarding the grouping of countries based on various environmental performance indicators. For instance, Arshad *et al.* (2020) evaluated the impact of ICT, trade, economic growth, financial development, and energy consumption on CO2 emissions in South and Southeast Asia from 1990 to 2014, testing the environmental Kuznets curve hypothesis and classifying countries into potential and advanced groups based on social development. Alvarado *et al*. (2018) classified 151 countries according to the strength of the relationship between their real per-capita output and carbon dioxide emissions. These studies then discuss the groups formed from the perspective of the indicator values considered. The perspective of this study differs; the descriptive approach through hierarchical clustering is a step in the process of studying the diffusion and contagion phenomena among countries concerning the environment and ecology.

The impact of the economic factors on environmental performance (Table 3) was first considered, followed by institutional factors (Table 4). The results show that more developed and richer countries perform better in terms of environmental performance. This is highlighted by the highly significant and positive coefficient of GDP per capita and the negative coefficient of the GDP growth rate. Thus, a higher GDP growth rate is a characteristic of less-developed countries, and its negative coefficient validates the assumption that these countries have less money to account for their environmental performance. The share of GDP obtained in industry affects EH positively, validating the results of the clustering process. Countries with intense industry, such as India, perform worse in terms of environmental protection. None of the proxies related to education were significant when introduced alone in the analysis. However, the most important result of the spatial approach is the confirmation of significant spatial processes occurring in environmental performance with contagion and diffusion. These are confirmed by the highly significant and positive coefficients of the spatial lag variables related to EH (*WEH*) and the spatial error correction term ($W\varepsilon$). As the *W* variable is the average value of the variable in the neighbors of each unit, as given by the spatial weights matrix, these results confirm that countries with similar environmental performance are neighbors and clusters in space and time, conditioned by the development level and importance of industry in the national economy. The positive coefficient of *WEH* shows that an increase in the environmental performance of neighbors leads to an increase in the central spatial unit, and vice versa. The positive $W\varepsilon$ coefficients point out the same but having as a source other factors than those considered.

Table 4 introduces the institutional factors used in the analysis. The clustering results emphasize a positive relationship between institutional quality and environmental performance, which was validated by the highly significant and positive coefficients of all institutional variables. Among them, the highest impact on EH has been proven to be the efficiency of the government and rule of law. Therefore, these two variables were selected for further introduction into the threshold panel analysis.

Significant contagion, diffusion, and clustering spatial processes are also confirmed, and both *WEH* and *Wε* have significant and positive coefficients, indicating that similar characteristics cluster over time. Consequently, there are phenomena of diffusion and contagion of environmental performance among neighboring countries or those in the same region.

High heterogeneity in economic performance reveals that economic and institutional factors have different effects on EH. Consequently, the analysis switches from a spatial panel approach to a threshold panel approach. Thus, economic variables, such as *GDP_CAP* and *IND_GDP*, are introduced as threshold variables and account for the existence of different regimes. The results presented in Table 5 confirm these assumptions. The threshold values were significant for both the variables. In the case of *GDP_CAP*, the threshold is 7.98 (logged value). Thus, there are two regimes: those countries with a logged GDP of less than 2920 USD (poorer) and those situated above it (richer). There is an inertial behavior of environmental performance, confirmed by the lag in the EH. This is significant only at the 10% level for the group below (poorer countries) and has a negative sign. This means that, over time, the environmental performance of poorer countries has decreased. Neither GDP per capita nor education were significant for poor countries. There are no directly comparable results in the literature, and there is evidence that GDP does not have a linear relationship with environmental performance or proposals for other indicators to replace it (Abbasi *et al.*, 2022). However, these results are consistent with intuition and economic logic. In environmentally developed countries compared with poorer ones, there are usually more developed industrial sectors to the detriment of agriculture. Therefore, the economic structure is incapable of promoting superior EH. Regarding education, in countries with moderate development compared with poor ones, there are average levels of education that focus on priority areas, such as basic engineering, economics, or administration. Similar mechanisms also explain the opposite signs of industry weight below and above the threshold. For less developed countries, the negative sign of *IND_GDP* indicates environmental degradation if the share of industry increases, as it generally involves the extractive, metallurgical, or chemical industries. Past *EH* values positively and significantly affect present values for richer countries. Their inertial behavior tends towards progressively increasing EH over time.

GDP_CAP is also significant and positive for the above-threshold group, conforming to previous results. Thus, for richer countries, economic performance has a greater impact on environmental performance. In highly developed countries, the increase in the share of services and industry includes advanced technologies at the expense of heavy industry. In addition, there are substantial financial reserves for environmental protection programs. Education also becomes significant with a positive coefficient, indicating that in countries in which citizens no longer care about subsistence and can also deal with other issues, investments in education foster care about the environment. Environmental education is available only in countries with a very high level of development, increasing the awareness of citizens and impacting the environment. Interestingly, *IND_GDP* was highly significant and positive at this time, indicating an increase in EH with an increase in the share of GDP obtained from industrial activities. These results may be because the types of industries present in richer countries are different from those in poorer countries and are less polluting, or that more measures are being taken for environmental protection and counterbalancing the pollution effects of industry. The positive sign for more developed countries indicates an increase in environmental performance because this is achieved by increasing the value of high-tech industrial products, often to the detriment of the production of goods with low added value. This may be because of the positive effect of the quality of institutions and administrative acts on EH, which is significantly higher in richer countries, as seen in the coefficients of *GOV_EFF* and *RULE_LAW* for the two regimes.

When the regimes are constructed with respect to the share of industry in the national economy, the threshold is 21.75. This means that the below-threshold regime comprises countries in which a maximum of 21.75% of the GDP is produced in industry, whereas the above-threshold regime comprises countries that rely much more on industrial activities. The lag of *EH* is not significant for any regime, whereas *GDP_CAP* is highly significant and positive for both regimes. GDP is more important for countries that are above the threshold, with higher importance placed on industry. The type of effect that the threshold variable has on the dependent variable is similar to the results for *GDP_CAP*. Countries with a lower GDP share from industry have a negative relationship with b EH. The less important industry is in the national economy, the more environmentally friendly it is. By contrast, for the above-threshold regime, there is a positive relationship between *IND_GDP* and EH. Education was highly significant and positive in both groups; however, its impact was higher in the above-threshold regime. Although *GOV_EFF* retained its positive impact in both groups, *RULE_LAW* was no longer statistically significant.

Discussions

The goal of the present research is to evaluate the impact of economic and institutional factors on environmental health by considering two main types of effects: spatial and nonlinear. As shown in the Results part, environmental performance is higher in countries that have a higher economic performance when the latter is assessed using the GDP, like in the study of de Mello Santos *et al*. (2022), for example. Similar findings belong to Matsumoto *et al*. (2020) for European countries and Hussain *et al.* (2022) for high-GDP countries. Additionally, this result is also in line with the classical theory of beta-convergence that states that richer countries, with higher GDP levels, should have, in time, lower GDP growth rates and vice-versa, to allow for the discrepancies between them and poorer countries to be diminished in time (see, for example, Bello & Ch'ng, 2022 or Mare *et al*., 2016). Additionally, the results also confirm the non-linear relationship between economic development and environmental performance that is emphasized in studies like the ones of Abbasi *et al*. (2022) or Lazăr *et al*. (2019).

The role of institutions in environmental performance has been extensively debated in the literature (see, for example, Le & Ozturk, 2020; Arshad *et al*., 2021; Alshehhi & Zervopoulos, 2023). In these studies, under the control of economic or educational factors, institutional determinants either have positive signs or are insignificant for the environment. These inconsistencies are probably due to the nonlinearity of causality relationships, which have been highlighted in this research, but were not accounted for in some of the studies. Our findings, novel in comparison to existing literature, reveal nonlinear impacts of GDP per capita and the industry's share in the economy on environmental health, along with positive impacts coming from institutional factors.

What is mostly important and adds to the literature is the fact that we introduce the threshold models, showing that there is not a uniform behavior of the analyzed countries, but there are different regimes, with different features, given by the development level proxied by the GDP per capita (similar to Lazăr *et al*., 2019) or the importance of industry in the national economy (de Mello Santos *et al*., 2022).

When dealing with spatial processes, results cannot be directly compared to previous studies since this issue has not been addressed before. However, the possible presence of contagion and diffusion processes in environmental issues have also been highlighted by Sun *et al.* (2021) or Yi (2023). Both studies try to explain such processes by talking about technological transfer among neighbors or green innovation, but without applying spatial analysis methods. Similar behavioral mimetics have been highlighted in other domains, such as by Mistur *et al*. (2023) for contagious COVID-19 policies or Cheng *et al*. (2021b) for information and communication technologies diffusion.

Conclusions

This study addressed the debate surrounding EH determinants, focusing on the scarcity of literature on spatial processes and interactions between countries. It evaluated the manifestation of spatial effects and identified different regimes associated with various variables.

The results highlight significant global clustering processes, revealing contagion and diffusion effects, where neighboring countries exhibit similar environmental performance influenced by economic and institutional factors, such as GDP, GDP growth rate, industry importance, and government effectiveness. Generally, more developed countries exhibit superior environmental performance. Despite this global pattern, this study identifies different regimes based on variables such as GDP per capita and the share of GDP obtained in industry. The existence of a threshold in the relationship between environmental performance and its determinants explains why an increasing share of industry generates environmental degradation in less-developed countries.

This study had some limitations. First, the quality and availability of data were not perfect. The behavior of a population, largely determined by cultural factors, is decisive for EH. However, the cultural dimensions are lacking in many countries. Moreover, they are static, limiting their use in dynamic econometric models. Regarding data quality, data concerning EH are based on specialists' estimations, adding subjectivity to the official real economic indicators. Second, the influence of certain factors may not have been accurately estimated. The industry indicator is a global measure that does not differentiate between industrial sectors. However, different sectors may have different impacts on the environment owing to diverse technologies and the workforce involved, among others. Similarly, education, measured as invested sums, fails to evaluate the quality of and orientation towards certain knowledge and skills. Third, the econometric instruments used were limited. A dynamic panel with a threshold is just one econometric tool that can highlight nonlinear causalities. Additionally, spatial econometrics may allow for other regression specifications that could lead to different results.

Future research should focus on eliminating the limitations of this study. The availability and quality of some data cannot be resolved in the short term. However, an approachable direction is provided by better exploitation of some of the influencing factors. The effects of industry can be better assessed by distinguishing between industrial branches or by evaluating regulations regarding emissions or energy consumption. Additionally, the role of education can be evaluated more comprehensively by quantifying its performance and structure. A proxy for these aspects can be provided by the quantity, quality, and orientation of international scientific publications. GDP is not a perfect measure of a country's standard of living; therefore, future studies could explore other measures of quality of life, such as poverty rate, income inequality, inflation, and purchasing power parity. From an econometric perspective, alternatives to explore the nonlinear connections between variables are polynomial regression, generalized additive models, nonlinear least squares, and spline models. In this study, spatial econometrics were used for only one specification. However, this branch of econometrics also has other types of regression models and quantifications of neighborhood relationships that approximate contagion and diffusion effects: the spatial Durbin model, geographically weighted regression, spatial lag of X model, and simultaneous autoregressive model, among others. In future research, these models or alternative specifications can be tested for the determinants of EH, and their results can be comparatively analyzed.

Future research could delve into the impact of both formal and informal institutional factors on allocative inefficiency in EH, thereby enriching the regression models used in this study. Additionally, incorporating national cultural factors can provide deeper insights into how these elements influence environmental policies and their effectiveness. The role of international pressures and their effects on public health in relation to environmental standards warrants further exploration, potentially uncovering the global dynamics of environmental governance. Moreover, employing public awareness estimates and structural indicators such as various measures of population education could offer a more nuanced understanding of the determinants of EH across different countries.

The identification of EH determinants and their nonlinear effects has implications for public policy. Awareness of the influencing factors emphasizes the need for national sustainability measures and the promotion of environmental protection. Recognizing the diffusion and contagion of environmental behavior supports educational and public awareness programs, facilitating positive changes on a large scale. National-level changes can echo transnationally and foster the exchange of knowledge and resources for more effective solutions. Understanding the mechanisms of environmental behavior diffusion allows for a coherent orientation towards high-risk areas, reducing negative impacts on human health and the environment. In conclusion, analyzing EH determinants and behavioral spread brings tangible benefits, contributing to more scientifically based and effective public policies in the environmental field.

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Annex

Table 1. Variables used and descriptive statistics

Variable	Explanations	Mean	Std. dev.	Min	Max
EH	Environmental health, assesses how well countries protect populations from environmental risks.	57.2	24.0	6.1	100
GDP_CAP	GDP per capita, in thousands of USD, period 2010-2022.	14607	20378	217	126426
GDP_GROWTH	Percentage increase of GDP per inhabitant, average values, period 2010-2022.	3.18	2.13	-2.70	12.25
IND_GDP	Share of the industrial sector in GDP, period 2010-2022.	27.4	11.4	6.6	77.3
EDUC_GDP	Financing of education, % of GDP, period 2010-2022.	4.35	1.60	1.12	12.84
EDUC_GOVEXP	Financing of education, % of government expenditure, period 2010-2022.	14.29	4.77	3.60	41.60
GOV_EFF	Government effectiveness: quality of public services, independence from political pressures, quality of policies.	-0.03	0.95	-2.23	2.29
RULE_LAW	Rule of law, the extent to which societal rules are followed and the likelihood of crime and violence.	0.07	0.96	-2.33	2.13

Table 2. Cluster description based on the centers — average values of the variables

Cluster	No. of countries	EH	GDP_CAP	IND_GDP	EDUC_GOVEXP	GOV_EFF	RULE_LAW
1	33	86.38	47851	25.76	13.26	1.43	1.42
2	48	66.49	11691	25.82	12.29	0.12	0.05
3	30	32.78	2849.9	33.95	10.93	-1.08	-1.09
4	53	44.76	3452.4	26.17	18.37	-0.44	-0.51

Source: own computation in STATA 16 and Tableau 2023.3

Table 3. Spatial panel regression — economic factors

Factor					
GDP_CAP	11.82*** (0.46)	-	-	-	-
GDP_GROWTH	-	-2.9*** (0.66)	-	-	-
IND_GDP	-	-	0.137** (0.07)	-	-
EDUC_GDP	-	-	-	0.26 (0.41)	
EDUC_GOVEXP	-	-	-	-	0.12 (0.09)
Constant	-42.23*** (4.36)	75.73*** (4.97)	-	-	-
Spatial effects					
WEH	1.43*** (0.09)	1.36*** (0.08)	0.83*** (0.066)	0.84*** (0.06)	0.82*** (0.07)
Wε	0.79*** (0.06)	0.78*** (0.07)	0.88*** (0.048)	0.83*** (0.06)	0.85*** (0.06)
Log likelihood	-4183.9	-4276.3	-3415.7	-3422.9	-3418.4
Wald Chi2 for spatial terms	302.7***	348.9***	763.3***	570.02***	616.01***
N	1155	1155	1155	1155	1155
Type of effects	Random	Random	Fixed	Fixed	Fixed

Note: Coef.*** (std. err.). ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Source: own computation in STATA 16.

Table 4. Spatial panel regression — institutional factors

Factor						
CTRL_CORR	10.5*** (1.04)	-	-	-	-	-
GOV_EFF	-	12.15** (1.07)	-	-	-	-
POL_STAB	-	-	3.61*** (0.93)	-	-	-
REG_QUAL	-	-	-	8.99*** (1.25)	-	-
RULE_LAW	-	-	-	-	11.08*** (1.14)	-
VOICE_ACC	-	-	-	-	-	8.92*** (1.12)
Constant	50.3*** (3.3)	51.62*** (3.08)	42.19*** (4.07)	51.35*** (3.8)	49.32*** (3.09)	43.3*** (3.86)
Spatial effects						
WEH	0.23*** (0.07)	0.16** (0.06)	0.39*** (0.07)	0.16** (0.08)	0.57*** (0.11)	0.34*** (0.07)
Wε	1.16*** (0.04)	1.17*** (0.04)	1.23*** (0.05)	1.15*** (0.04)	0.97*** (0.009)	1.19*** (0.04)
Log likelihood	-4268.7	-4266.4	-4303.9	-4290.7	-4283.9	-4285.3
Wald Chi2 for spatial terms	1022.6***	945.01***	557.6***	953.1***	14561.02***	751***
N	1155	1155	1155	1155	1155	1155
Type of effects	Random	Random	Random	Random	Random	Random

Note: Coef.*** (std. err.). ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Source: own construction in STATA 16.

Table 5. Threshold panel regression

Factor	Threshold lnGDP_CAP	Threshold IND_GDP
Threshold	7.98*** (0.35)	21.75*** (3.04)
LagEH_b	-0.62* (0.35)	0.032 (0.47)
lnGDP_CAP_b	5.12 (29.85)	39.86*** (15.07)
IND_GDP_b	-3.18** (1.3)	-7.98** (3.73)
EDUC_GOVEXP_b	0.978 (1.11)	6.87*** (2.09)
GOV_EFF_b	178.2*** (41.11)	82.09*** (29.53)
RULE_LAW_b	89.2** (34.84)	-1.87 (33.39)
constant_b	-752.6*** (275.7)	206.69 (134.73)
LagEH_a	1.67*** (0.36)	0.3 (0.66)
GDP_CAP_a	66.06* (38.11)	56.07*** (15.18)
IND_GDP_a	4.21*** (1.52)	8.57** (3.89)
EDUC_GOVEXP_a	2.58* (1.37)	8.18*** (2.09)
GOV_EFF_a	262.47*** (39.21)	104.28** (40.29)
RULE_LAW_a	130.85*** (49.42)	70.4 (50.62)
N	1155	1155

Note: Coef.*** (std. err.). ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.
b = below the threshold and a = above the threshold

Source: own construction in STATA 16.

Figure 1. Spatial distribution of EH — in 2010 and 2022

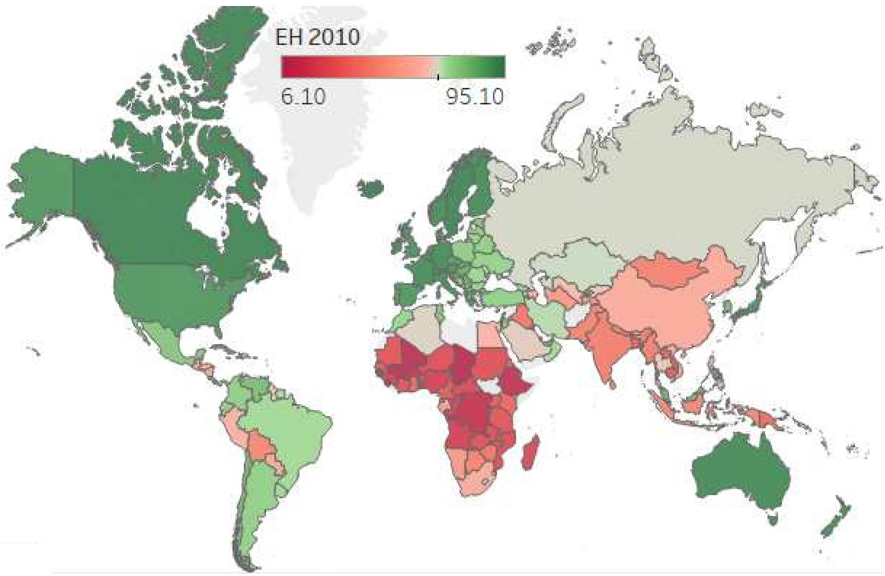
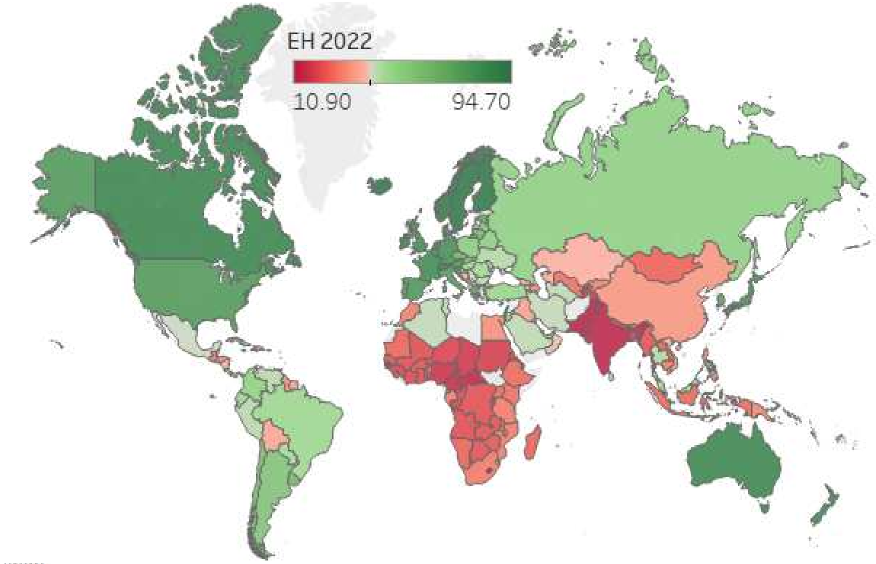
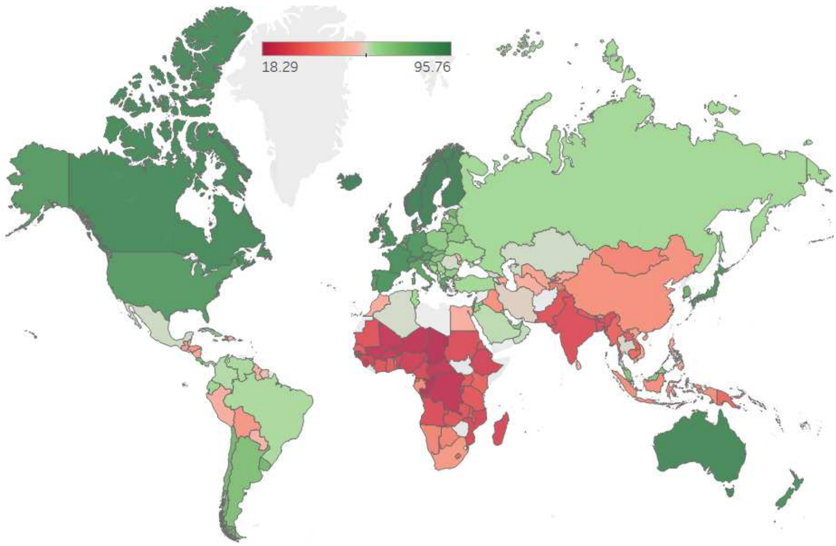


Figure 1. Continued



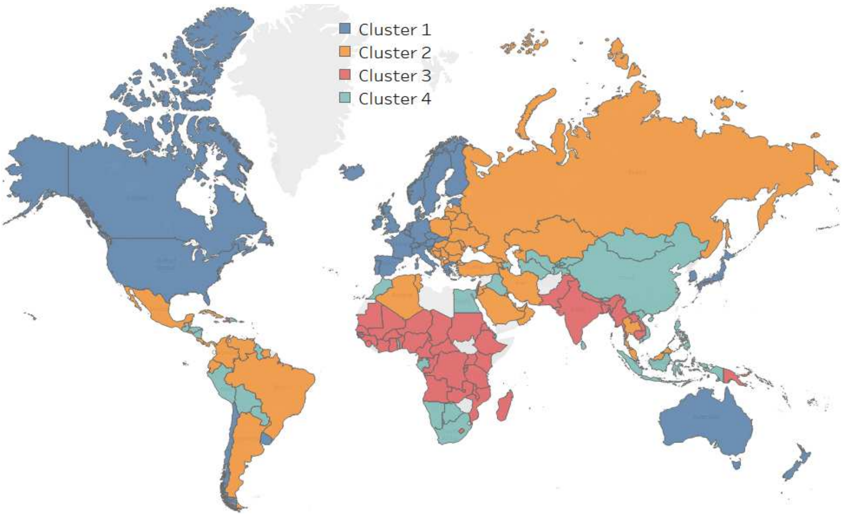
Source: own construction in Tableau 2023.3

Figure 2. Spatial distribution of EH – average value for the period analyzed



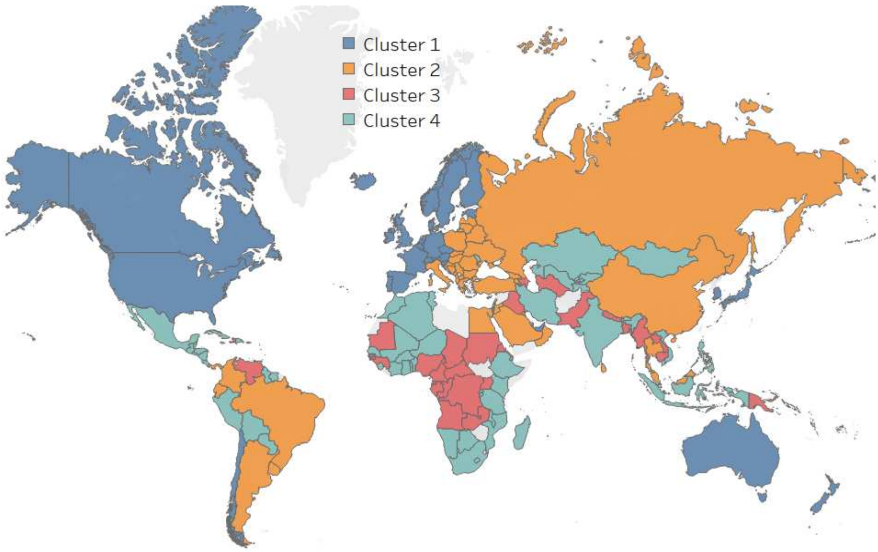
Source: own construction in Tableau 2023.3

Figure 3. Spatial clustering of countries based on environmental performance – average values for 2010–2022



Source: own construction in Tableau 2023.3.

Figure 4. Spatial clustering of countries based on environmental performance and its main drivers — average values for 2010–2022



Source: own construction in Tableau 2023.3.