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Re-visiting the Environmental Kuznets Curve: Unlocking the Ecological Roles of Environmental Taxes and Geopolitical Risk

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Abstract


Environmental sustainability remains a critical challenge for the Organization for Economic Co-operation and Development (OECD), where advanced economic structures coexist with high levels of resource consumption and ecological pressure. This study contributes to the literature by integrating economic growth (GDP), environmental taxes (ETA), Geopolitical Risk (GPR), and Technological Innovations (TEI) within a unified framework, while emphasizing the novel moderating role of GPR on ecological sustainability, measured by the Load Capacity Factor (LCF). Using a balanced panel dataset of 38 OECD countries over the period 2010-2024, the study employs the two-step System Generalized Method of Moments (System GMM) estimator to address endogeneity and dynamic relationships. The findings reveal that GDP exhibits a nonlinear U-shaped relationship with environmental quality, initially reducing environmental quality and later improving it. ETA and TEI both contribute positively to environmental quality, highlighting the importance of fiscal instruments and innovation-driven transitions in promoting sustainability. GPR also shows a positive direct effect on environmental quality, suggesting that heightened uncertainty may reduce economic and industrial pressures. Importantly, the interaction effects indicate that GPR strengthens the positive impacts of both ETA and technological innovation, amplifying their effectiveness in improving environmental quality within OECD economies. These findings suggest that environmental policies are more effective under higher GPR conditions, implying that policymakers should not weaken environmental commitments during periods of uncertainty.

Keywords: Economic growth, Environmental taxes, Geopolitical risk, Technological innovations, Environmental sustainability.

1 | Introduction

Environmental quality has increasingly become a central concern in modern economic discourse, particularly within advanced economies where rapid industrialization and high levels of consumption exert substantial pressure on natural ecosystems. In developed economic systems, growth is often accompanied by intensified energy use and environmental degradation, raising critical questions about the sustainability of prevailing development trajectories [1], [2]. Organization for Economic Co-operation and Development (OECD) countries, in particular, represent a unique context due to their dominant role in global production,

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technological advancement, and environmental policy innovation [3]. These economies are characterized by sophisticated institutional frameworks and proactive environmental governance, making them ideal for examining the complex interplay between economic growth and environmental sustainability [4]. Consequently, investigating environmental dynamics within this group offers valuable insights into sustainable development pathways at both regional and global levels.

Geopolitical Risk (GPR) has increasingly been recognized as a critical factor shaping environmental outcomes, particularly in globally integrated, economically advanced regions [5], [6]. In the context of OECD economies, geopolitical tensions manifest through multiple transmission channels, including trade disruptions, energy supply shocks, and heightened macroeconomic uncertainty, all of which have direct and indirect consequences for environmental quality [7], [8]. For instance, periods of geopolitical instability often lead to volatility in energy markets, prompting countries to prioritize energy security over environmental sustainability, thereby increasing reliance on carbon-intensive energy sources [9]. Furthermore, such uncertainties tend to delay or weaken the implementation of environmental regulations, as governments redirect resources toward immediate economic stabilization and national security concerns. Beyond policy responses, GPR also influences private-sector behavior by discouraging long-term investments in renewable energy and green infrastructure, which are essential to improving environmental performance [10], [11]. This dynamic is particularly relevant for OECD countries, where environmental progress is closely tied to stable policy environments and sustained investment flows. Therefore, examining the environmental implications of GPR provides a deeper understanding of how external shocks can reshape sustainability trajectories in advanced economies.

Technological innovation constitutes a fundamental pillar in the transition toward environmentally sustainable economic systems, especially in advanced economies characterized by high research and development intensity [12]. Within OECD countries, innovation-driven growth has facilitated the adoption of cleaner technologies, enhanced energy efficiency, and reduced the environmental footprint of industrial activities [13]. Theoretical perspectives suggest that technological progress not only mitigates environmental degradation but also decouples economic growth from resource consumption through efficiency gains and structural transformation [14]. Empirical evidence further indicates that investments in green innovation, such as renewable energy technologies and low-carbon production processes, significantly contribute to environmental improvement [15]. However, the environmental benefits of technological innovation are contingent upon supportive policy frameworks and institutional quality, as well as the direction of innovation itself, whether it is environmentally friendly or resource-intensive [16]. In OECD economies, where technological capabilities are relatively advanced, innovation can serve as a powerful mechanism for achieving sustainable development goals. Nevertheless, disparities in innovation efficiency and policy alignment across countries necessitate a more nuanced examination of its environmental implications.

Environmental Taxes (ETA) are widely regarded as one of the most effective market-based instruments for addressing environmental degradation and promoting sustainable economic behavior. By incorporating the social cost of pollution into market prices, these taxes create economic incentives for firms and households to reduce emissions and adopt cleaner technologies [17]. Environmental taxation has played a significant role in shaping environmental outcomes by encouraging energy efficiency and reducing dependence on fossil fuels [18]. Moreover, ETA generate public revenues that can be strategically reinvested in green infrastructure, renewable energy development, and technological innovation, thereby reinforcing their positive environmental impact [19], [20]. Despite these advantages, the effectiveness of ETA depends critically on their design, implementation, and interaction with other policy instruments. For instance, poorly designed tax structures may lead to unintended economic distortions or social inequalities, potentially undermining public support for environmental policies. In OECD economies, where institutional capacity is relatively strong, ETA offer a promising avenue for achieving both environmental and economic objectives, provided they are integrated into a comprehensive and coherent policy framework [21].

Recent advances in environmental economics have highlighted the importance of accounting for interactions among key economic and political variables when analyzing environmental outcomes. In this regard, GPR plays a dual role by exerting both direct and indirect influences on environmental quality. Beyond its immediate impact, GPR can significantly alter the effectiveness of environmental policies and technological innovation through complex moderating mechanisms [22]. For example, during periods of heightened geopolitical tension, governments may deprioritize environmental taxation policies in favor of short-term economic stability, thereby weakening their intended environmental benefits [5]. Similarly, increased uncertainty can discourage private and public investments in green technologies, reducing the positive impact of technological innovation on environmental quality [13]. These interaction effects are particularly pronounced in OECD countries, where environmental outcomes are closely linked to policy consistency and innovation-driven growth. Consequently, incorporating GPR's moderating role provides a more comprehensive framework for understanding environmental dynamics. It allows for a deeper exploration of how external uncertainties shape the effectiveness of key sustainability drivers.

Several structural and empirical considerations justify selecting 38 OECD countries. These economies are characterized by advanced institutional frameworks, well-developed environmental policies, and high levels of technological innovation, making them particularly suitable for analyzing the determinants of environmental quality [12]. Furthermore, the availability of consistent, high-quality data enhances the reliability of empirical estimates in cross-country analyses. OECD countries also account for a substantial share of global carbon emissions, and their policy decisions have far-reaching implications for global environmental sustainability. In addition, these countries have been at the forefront of implementing ETA and promoting green technological transitions, providing a robust context for examining the effectiveness of policies and innovation-driven environmental improvements.

This study contributes to the existing literature in several important ways. First, it employs the Load Capacity Factor (LCF) as a comprehensive proxy for environmental quality, offering a broader perspective than conventional indicators such as CO₂ emissions. Second, it integrates GPR, technological innovation, and ETA into a unified empirical framework within the Environmental Kuznets Curve (EKC) hypothesis. Third, a key novelty lies in examining the moderating role of GPR in shaping the effects of ETA and technological innovation on environmental quality. Finally, by focusing on OECD countries, the study provides policy-relevant insights grounded in advanced economic and institutional settings.

The primary objective of this study is to investigate the impact of economic growth, GPR, technological innovation, and ETA on environmental quality, proxied by the LCF, in selected OECD countries covering 2010-2024. Additionally, the study aims to explore the moderating role of GPR in influencing how ETA and technological innovation affect environmental sustainability. In line with these aims, this study seeks to address the following key questions: 1) Does the EKC hypothesis hold in the context of LCF for OECD countries? 2) What is the impact of GPR on environmental quality? 3) How do technological innovation and ETA influence LCF? and 4) Does GPR moderate the relationships between these variables and environmental quality?

The remainder of this study is structured as follows. Section two reviews the empirical literature concerning the impact of the key variables under investigation on environmental quality. Section three outlines the data sources, model specification, and methodological framework employed in the analysis. The empirical findings are presented in section four. Finally, the results are discussed in relation to the existing literature, and the study concludes with policy recommendations based on the main findings.

2 | Literature Review

When the empirical literature is examined, the mixed results of a limited number of studies on the connection between environmental-related taxes and EFP or ecological sustainability stand out. Analyzing OECD countries, Aydin [23] argues that environmental-related taxes are ineffective, whereas Rafique et al. [24] report the opposite. According to the study by Rafique et al. [24], empirical results reveal that environmental-related

taxes, economic growth, foreign direct investment, energy use, urbanization, renewable energy, and industrialization significantly influence the long-term ecological footprint in OECD countries. The dynamics of the studied variables changed over time. In the short term, these dynamics are mixed, while in the long term, they remain similar across OECD countries. This argument is attributed to varying levels of renewable energy use and industrialization progress in OECD countries. Esen et al. [1] for EU countries and Fang et al. [25] for China imply an inverted U-shaped relationship between ET and EFP. As a matter of fact, Esen et al. [1] and Fang et al. [25] found a nonlinear threshold effect of environmentally related taxes on ecological balance indicators. Yavuz and Ergen [26] argue that environmental-related taxes are ineffective at reducing EFP in the G-20 and Turkey, respectively. While Javed et al. [27] highlight the significant role of ETA in mitigating EFP, Aydin et al. [28] provide contrasting evidence, suggesting that these fiscal instruments are ineffective in achieving environmental objectives.

Environmental technology alleviates the environmental impact of economic activities by increasing energy efficiency and maintaining competitiveness. Environmental technology, also called green innovation, helps achieve the SDGs by balancing the link between economic growth and ecological structure [18]. However, empirical evidence on the link between environmental technology and EFP is mixed. The first view suggests that environmental technology contributes to environmental sustainability by reducing EFP [14], [15], [18]. Afshan et al. [14] examine the impact of renewable energy transition, ecological innovation, and environmental policy stringency on the ecological footprint of OECD economies over the period 1990–2017 within the framework of the EKC hypothesis. Employing the advanced Method of Moments Quantile Regression (MM-QR) approach, their empirical results reveal a consistently negative relationship between the selected green variables and the ecological footprint across all quantiles.

Furthermore, the findings provide empirical support for the validity of the EKC hypothesis in the sampled economies. The other view reveals positive or insignificant results between environmental technology and EFP [13], [28], [29]. Contrary to theoretical expectations, Anu et al. [13] document a positive linkage between green innovation and the ecological footprint, thereby challenging the presumed environmental effectiveness of green innovation. Aydin et al. [28] investigated the impact of green patents on the ecological footprint in European Union countries with the framework of the EKC hypothesis. According to the results, the EKC hypothesis is valid only in Finland.

Additionally, green patents reduce the ecological footprint in Italy, while they increase in Finland, Germany, and the Netherlands. The contribution of ecological technologies to environmental degradation is also captured in [29]. Environmental technology has a direct impact on environmental degradation in China.

The effects of GPR on environmental quality have become a central focus for researchers [9]. For example, Syed et al. [30], using a panel quantile regression approach for the BRICST economies, found that increases in GPR tend to raise CO₂ emissions at lower quantiles, whereas at higher quantiles, the effect reverses and emissions decline. In examining the link between GPR and environmental degradation, Riti et al. [31] reported mixed findings: a positive association at the aggregate level but a negative relationship when disaggregated. Similarly, Sweidan [32], applying a two-way Prais-Winsten regression model, found that the relationship between GPR and CO₂ emissions encompasses both positive and negative effects, making it difficult to definitively conclude whether GPR exacerbates environmental degradation. In the same vein, Zhao et al. [33] also identified inconsistent results; for instance, rising GPR reduces CO₂ emissions in South Africa and Russia, while in China, India, and Brazil, a decline in GPR is associated with lower emissions. On the other hand, Hashmi et al. [34] employed a bootstrapped ARDL framework and demonstrated that an increase in geopolitical tensions is associated with higher long-term global CO₂ emissions. The theoretical framework of the study is presented in *Fig. 1*.



Fig. 1. Theoretical framework of the study.

3 | Data and Methodology

3.1 | Data

This study investigates the effects of economic growth (GDP), ETA, GPR, and Technological Innovations (TEI) on Load Capacity Factor (LCF) in 38 selected OECD economies covering 2010-2024. The dependent variable of the study, LCF, is measured as the ratio (biocapacity / ecological footprint). The independent variables, such as GDP, are measured as gross domestic product per capita (constant US \$2015); ETA is the percentage of GDP; GPR is the Geopolitical Index; and TEI is calculated using patent applications by residents and non-residents. The data for ETA and TEI are sourced from the OECD database, whereas the information for GPR is obtained from Policyuncertainty.com, and the GDP data are sourced from the WDI database for the period from 2010 to 2024 for selected OECD economies. *Table 1* presents the data sources and measurement scales of the variables in detail.

Table 1. Description of the variables.

Variable	Symbol	Criterion	Source
Ecological footprint	LCF	Global hectares per person	GFN
Economic growth	GDP	Per capita 2015 \$ constant	WDI
Environmental taxes	ETA	% GDP	OECD
Geopolitical risk	GPR	Index	Policyuncertainty.com
Technological innovations	TEI	% of total patents	OECD

Note: GFN means Global Footprint Network, WDI means World Development Indicators, and OECD means Organization for Economic Co-operation and Development.

3.2 | Model and Methodology

The paper aims to examine the impact of key variables on LCF across the selected OECD economies. Given modern-day challenges, the study develops a unique model of environmental quality, as outlined in *Eq. (1)* below.

$$LCF = f(GDP, ETA, GPR, TEI), \tag{1}$$

The model shows the dependency of environmental quality (LCF) on economic growth (GDP), ETA, GPR, and TEI. *Eq. (1)* shows the functional form of the model. To overcome the econometric challenges, this study employs the Generalized Method of Moments (GMM) framework developed by Arellano and Bond [35], which is well-suited for dynamic panel data models.

The GMM estimator effectively addresses endogeneity by using internal instruments based on lagged values of the explanatory variables, while also accommodating heteroskedasticity and serial correlation in the error structure. The choice of GMM is further justified by the dataset's structure, where the number of cross-

sectional units (N) exceeds the time dimension (T), a setting in which GMM estimators are particularly efficient and appropriate. Nevertheless, the conventional difference GMM estimator may suffer from weak-identification problems, especially when the variables exhibit high persistence. To address this limitation, the System GMM estimator proposed by Blundell and Bond [36] is employed. This approach augments the standard difference GMM by incorporating an additional set of moment conditions in levels, thereby improving instrument strength and enhancing estimation efficiency. The System GMM estimator combines equations in first differences and levels, enabling more precise and robust parameter estimation in dynamic panel data settings. The reliability of GMM estimation results depends on the validity of the underlying assumptions and instruments. Accordingly, the Arellano-Bond test is conducted to verify the absence of second-order serial correlation in the differenced error terms.

In contrast, the Sargan or Hansen test of overidentifying restrictions is employed to assess the overall validity of the instrument set. Given its superior efficiency and robustness relative to alternative estimators, the System GMM approach is adopted to estimate the empirical models in this study. Following the theoretical framework and drawing on established empirical literature and inspired by Fakher et al. [37] and Fakher et al. [38], the baseline dynamic specification of the model is expressed as:

$$\ln LCF_{it} = \alpha_0 + \delta \ln LCF_{i,t-1} + \theta \ln X_{it} + \varepsilon_{it}, \quad (2)$$

LCF_{it} represents environmental quality, and X_{it} is a vector of explanatory variables including economic growth (GDP), ETA, GPR, and TEI. To capture the moderating role of GPR, the model is extended as follows:

$$\ln LCF_{it} = \alpha_0 + \gamma \ln LCF_{i,t-1} + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP2_{it} + \beta_3 \ln ETA_{it} + \beta_4 \ln TEI_{it} + \beta_5 \ln GPR_{it} + \beta_5 \ln(ETA_{it} \times GPR_{it}) + \beta_6 \ln(TEI_{it} \times GPR_{it}) + \varepsilon_{it}. \quad (3)$$

In the above model, interaction terms are introduced to explicitly examine the moderating role of GPR on the relationships among ETA, TEI, and LCF.

4 | Empirical Findings and Discussion

For the first step, the results of the statistical analysis for data description are presented in *Table 2*.

Table 2. Statistics for data description.

	LCF	GDP	ETA	GPR	TEI
Mean	2.28	7.618	8.31	0.351	0.883
Maximum	3.44	11.558	12.81	5.45	1.517
Minimum	-2.88	7.984	7.09	0.089	0.520
Skewness	0.338	2.081	-0.08	4.181	0.068
Kurtosis	2.558	12.118	3.89	19.281	2.781
Jarque-Bera	6.58*** (0.001)	8.22*** (0.001)	1.81*** (0.000)	4.08*** (0.000)	9.28*** (0.000)

The descriptive statistics in Table 2 indicate that the variables exhibit significant departures from normality. It is reflected in the skewness coefficients, where several variables, particularly GDP (2.081) and GPR (4.181), display substantial positive skewness, indicating the presence of extreme values. Additionally, the kurtosis values for GDP (12.118) and GPR (19.281) are considerably higher than the normal benchmark of 3, suggesting leptokurtic distributions with heavy tails and potential outliers. Moreover, the Jarque-Bera test statistics are significant at the 1% level for all variables, strongly rejecting the null hypothesis of normality. These findings confirm the presence of non-normality, heteroskedasticity, and distributional asymmetry within the dataset. From an econometric standpoint, such characteristics limit the applicability of conventional estimation techniques based on strict classical assumptions. Therefore, the use of the System GMM estimator is well justified, as it is robust to non-normality and heteroskedasticity, and effectively addresses potential endogeneity and dynamic relationships among variables. Consequently, the data's distributional properties provide strong empirical support for adopting the GMM approach in this study.

Table 3. The result of the system GMM estimation.

Variables	Model-1	Model-2	Model-3
lnGDP	-0.1509*** (0.003)	-0.1488*** (0.002)	-0.1491*** (0.003)
lnGDP ²	0.0666** (0.011)	0.0691** (0.012)	0.0677** (0.010)
lnETA	0.0338*** (0.002)	0.0359*** (0.003)	0.0347*** (0.001)
lnTEI	0.0216** (0.013)	0.0220** (0.032)	0.0218** (0.020)
lnGPR	0.0118** (0.011)	0.0121** (0.021)	0.0120** (0.010)
ln (ETA*GPR)	-	0.007** (0.033)	-
ln (TEI*GPR)	-	-	0.005** (0.031)
Diagnostic Tests			
Sargan test	117.12	248.19	339.44
AR(2) test	31.066	44.069	46.019
Hansen test	1.000***	1.000***	1.000***

Note: The probability values are shown in brackets (), while *** and ** indicate significance at the 1 % and 5 % levels, respectively.

Table 3 reports the results of the System GMM estimation, which examines the effects of economic growth, ETA, GPR, and TEI on ecological sustainability, measured by LCF. The relationship between economic growth (GDP) and environmental quality is nonlinear, following a U-shaped pattern. The negative coefficient of GDP combined with the positive coefficient of GDP² indicates that at lower levels of income, economic growth deteriorates environmental quality. It reflects the fact that even in OECD countries, initial stages of economic expansion are associated with increased production activity, energy consumption, and transport demand, all of which exert pressure on environmental systems. However, as income rises further, the relationship reverses, and economic growth begins to improve environmental quality. This turning point can be explained by the strong institutional frameworks in OECD economies, which enable higher income levels to support stricter environmental regulations, greater investment in clean technologies, and a structural shift toward less pollution-intensive service sectors.

ETA have a positive, statistically significant effect on environmental quality across all specifications. This finding confirms that environmental taxation is an effective policy instrument in OECD countries. In these economies, ETA are supported by strong governance structures, high administrative capacity, and relatively high environmental awareness among firms and households. As a result, such taxes effectively internalize environmental externalities, encouraging a shift toward cleaner production processes and more sustainable consumption patterns, thereby enhancing environmental quality. Technological innovation also has a positive and significant impact on environmental quality. It suggests that innovation in OECD countries is largely aligned with environmental objectives. Given the strong emphasis on research and development, climate policy integration, and green transition strategies, technological progress tends to support energy efficiency improvements, cleaner production methods, and the diffusion of environmentally friendly technologies. Consequently, innovation contributes directly to enhancing environmental quality rather than undermining it.

GPR, however, has a positive coefficient, indicating that it improves environmental quality in OECD countries. This result may appear counterintuitive, but it can be explained by structural and behavioral adjustments under geopolitical tension. In OECD economies, rising GPR often leads to a reduction in economic activity, lower trade intensity, and a slowdown in industrial production, driven by uncertainty. These effects reduce energy consumption and emissions-intensive activities, thereby improving environmental quality in the short to medium term. In addition, geopolitical uncertainty may accelerate policy responses to energy efficiency and strategic resource management, further advancing environmental improvements.

The interaction terms provide deeper insights into how GPR modifies the effectiveness of environmental taxation and technological innovation. The interaction between ETA and GPR (ETA × GPR) is positive and statistically significant. It indicates that GPR strengthens the positive effect of ETA on environmental quality. In OECD countries, periods of geopolitical tension often increase government attention to resource efficiency and economic resilience. Under such conditions, ETA become more strictly enforced or more effectively transmitted into behavioral changes, as firms and households face stronger incentives to optimize

energy use and reduce dependence on external resources. As a result, the effectiveness of environmental taxation in improving environmental quality is amplified when GPR is high. Similarly, the interaction between technological innovation and GPR ($TEI \times GPR$) is also positive and significant. It suggests that GPR enhances the environmental benefits of technological innovation. In OECD countries, geopolitical uncertainty tends to accelerate investment in strategic and efficiency-enhancing technologies, particularly those related to energy security, digitalization, and resource optimization. These innovations often have strong spillover effects on environmental performance, leading to reduced energy intensity and improved environmental outcomes. Therefore, innovation becomes more environmentally effective in contexts of higher geopolitical pressure. A schematic summary of the empirical findings is presented in *Fig. 2*.

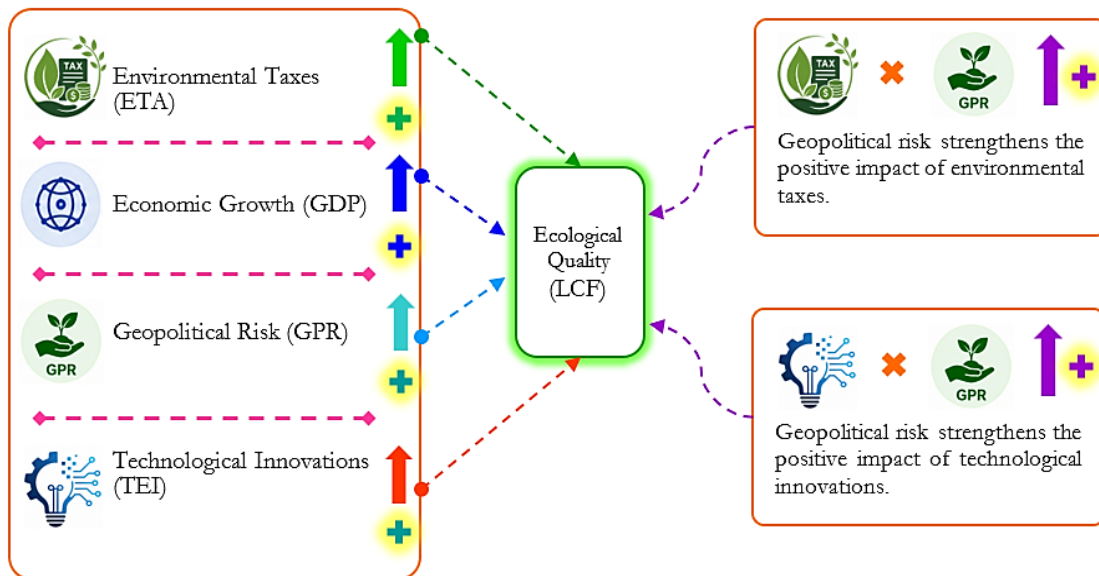


Fig. 2. Schematic presentation of the summary of empirical findings.

5 | Conclusion and Policy Implications

5.1 | Conclusion

This study investigates the determinants of environmental quality in OECD countries, focusing on the interconnections among environmental sustainability, economic development, technological progress, and geopolitical uncertainty, which constitute a critical, policy-relevant nexus. By integrating environmental taxation, technological innovation, and GPR within a unified empirical framework and accounting for their potential interactive effects on environmental quality, the analysis provides a more comprehensive understanding of the multifaceted drivers of environmental outcomes that have received limited attention in previous studies. The empirical analysis is conducted for OECD countries over 2010-2024 and employs the two-step System GMM estimator. The main results reveal that a complex set of economic and non-economic factors shapes environmental quality. Economic growth exhibits a nonlinear U-shaped relationship with environmental quality, initially reducing and later improving environmental conditions. ETA and technological innovation both contribute to improving environmental quality, underscoring the importance of fiscal instruments and innovation-driven transitions in promoting sustainability. GPR also shows a positive direct effect on environmental quality, suggesting that heightened uncertainty may reduce economic and industrial pressures. Importantly, the interaction effects indicate that GPR strengthens the positive impacts of both ETA and technological innovation, amplifying their effectiveness in improving environmental quality within OECD economies.

5.2 | Policy Implications

The empirical results provide several important policy implications for OECD countries, with particular emphasis on the role of GPR in shaping the effectiveness of environmental policies. First, the U-shaped relationship between economic growth and environmental quality suggests that environmental degradation is more severe at early stages of income growth. At the same time, higher-income levels are associated with environmental improvements. It implies that policy responses should be stage-specific: stricter environmental regulations and efficiency standards are needed during lower-income phases. At the same time, innovation-driven and market-based instruments become more effective as economies mature. Second, ETA are confirmed as an effective tool for improving environmental quality. Policymakers should therefore maintain and expand green tax schemes, while ensuring robust enforcement mechanisms and the efficient use of tax revenues to support green investments and accelerate the transition toward low-carbon production and consumption patterns. Third, technological innovation plays a crucial role in enhancing environmental quality. This argument highlights the importance of sustained public support for green R&D, digital transformation, and the diffusion of clean technologies as core pillars of environmental policy in advanced economies.

Most importantly, the results emphasize the critical role of interaction effects with GPR. The positive and significant interaction between ETA and GPR ($ETA \times GPR$) indicates that geopolitical tensions enhance the effectiveness of environmental taxation. This argument likely occurs because uncertainty increases policy enforcement, encourages resource efficiency, and strengthens behavioral responses by firms and households. Similarly, the positive interaction between technological innovation and GPR ($TEI \times GPR$) suggests that GPR amplifies the environmental benefits of technological innovation, particularly by accelerating investment in energy security, efficiency-enhancing technologies, and strategic technological adaptation.

Authors' Contributions

S. H.: Writing-original draft, Methodology, Data Curation, Conceptualization, Software, and Visualization, and Validation. M. J.: Validation, Writing-Review & Editing, and Formal Analysis. The authors have read and agreed to the published version of the manuscript.

Data Availability

The data is available on request from the corresponding author.

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Conflict of Interest

There are no competing interests to declare.

Consent for Publication

The authors have given consent for the publication of this manuscript.

Ethics Approval and Consent to Participate

The authors confirm that this research did not involve human participants or animal subjects.

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