International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2026, 16(1), 661-671.

Exploring Environmental Mitigation Strategies for CO_2 Emissions in OECD Countries: Does Geopolitical Risk Affect Their Effectiveness?

Kahouli Zohra[1]*, Radhouane Hasni[2], Ouerghi Imen[2]

[1]Imam Mohammad Ibn Saud Islamic University (IMSIU), Saudi Arabia, [2]University of Manouba, Higher School of Commerce, QuAnLab LR24ES21, Mnouba, Tunisia. *Email: kahouli_zohra@yahoo.fr

Received: 01 July 2025 **Accepted:** 27 October 2025 **DOI:** https://doi.org/10.32479/ijeep.21914

ABSTRACT

The World Economic Forum's Global Risks 2024 report identifies four key strategies for mitigating climate threats: Localized strategies, breakthrough endeavours, collective actions and cross-border coordination. It also highlights the interplay between two major crises: climate and conflict. Consequently, in a world where environmental and geopolitical risks (GPR) are increasingly interlinked, climate strategies must take this complex dynamic into account. In order to assess the effectiveness of the proposed solutions, taking into account their interdependence with GPR, our study analyses the direct impact of environmental policy stringency (EPS), environment-related technologies (ERT), renewable energies (RE) and political globalisation (PG) on CO_2 emissions, as well as the direct impact of GPR and its interaction with these solutions. Results, obtained using an ARDL-PMG approach applied to OECD countries during the period 2000-2020, show that these solutions reduce emissions. However, the direct impact of GPR increases emissions, and its interaction with other solutions negates their benefits, ultimately raising emissions. The study proposes policy recommendations and highlights the importance of considering the negative impact of GPR on CO_2 emissions, as well as its negative interaction with environmental solutions, in order to increase the effectiveness of proposed measures and ensure that long-term emissions reduction targets are met.

Keywords: Environmental Risk, Geopolitical Risk, PMG ARDL, OECD Countries
JEL Classifications: Q5,Q54,Q58,O13

1. INTRODUCTION

In its latest report, Global Risks 2024, the World Economic Forum (WEF, 2024) highlights two interconnected crises that are shaping the global landscape: climate disruption and geopolitical conflict. Environmental risks, such as pollution and CO_2 emissions, are among the most pressing concerns, threatening to irreversibly compromise the future. At the same time, geopolitical tensions, exacerbated by conflicts in key regions such as Ukraine, the Middle East and Taiwan, have led to an unstable global climate, an erosion of trust between nations and growing insecurity. These complex geopolitical dynamics, the report argues, threaten to cripple the world's ability to cope with ongoing shocks and call for in-depth reflection on the interactions between climate governance and geopolitical issues in order to avoid a spiral of converging crises. Faced with these challenges, the WEF (2024) proposes a set of solutions comprising four main strategies for mitigating environmental risks, the impact of which on environmental quality has been extensively studied empirically. First, local strategies based on stringent national environmental regulations offer a flexible and pragmatic response to environmental challenges, making it possible to reduce pollution without the lengthy delays associated with international negotiations. Empirical studies, often using the environmental policy stringency (EPS) as a key indicator to evaluate this solution, confirm its crucial role in improving environmental quality. For example, studies by Ahmed (2020), Acheampong (2022), Frohm et al. (2023), Mihai et al. (2023), Saqib and Dinca (2024), Fatima et al. (2024), Rehman et al. (2024), Sohag et al. (2024) illustrate the positive impact of stringent environmental policies on reducing CO_2 emissions and promoting sustainable practices. Second, technological breakthroughs, as reflected by investment in environmental R&D, play a crucial role in reducing environmental risks. Studies by Chen and Lee (2020), Hussain and Dogan (2021), Mongo et al. (2021), Hussain et al. (2021), Dehdar et al. (2022), Alataş (2022), Ahmed et al. (2022), Kwilinski et al. (2024) show that environment-related technologies (ERT) can reduce CO_2 emissions, although their effectiveness may vary according to economic contexts, income levels and technological capabilities. Thirdly, collective action based on the idea of renewable energy consumption through lifestyle and consumption changes can, if Member States act simultaneously, change market dynamics and catalyse climate change mitigation, as demonstrated by the transition to sustainable mobility, including the reduction of internal combustion engine vehicles and air travel. Empirical studies in this context show that renewable energy consumption has a positive impact on environmental quality. (Cengiz et al., 2022; Farooq et al., 2022; Acheampong et al., 2023; Sultana et al., 2023; Ben Jebli et al., 2024; Kahouli et al., 2025). Fourth, cross-border coordination, based on mutual restraint mechanisms such as agreements to limit the use of energy-intensive products and international treaties such as the Kyoto Protocol (1997), the UNFCCC (1992) and the Paris Agreement (2015), is essential for responding to environmental risks. Empirical studies use the political globalisation index (PG), which reflects this coordination and the increasing interconnectedness of nations through diplomatic, organisational and legal networks, to determine the impact on environmental quality (Mehmood, 2021; Muhammad and Khan, 2021; Jahanger, 2022; Nan et al., 2022; Jahanger et al., 2023; Feng et al., 2024).

Although these solutions have been proposed to mitigate environmental risks, their effectiveness needs to be reassessed in the context of geopolitical risk (GPR), which strongly influence environmental policies. Geopolitical risk has a direct impact on environmental quality (Chen et al., 2023; Ma et al., 2022), exacerbates inequalities in CO_2 emissions (Bergougui et al., 2024), reduces pollution in some cases (Husnain et al., 2022), but sometimes impedes overall progress (Kartal et al., 2024; Luo et al., 2024). It also disrupts the effectiveness of environmental policies by hindering international cooperation and the adoption of strong environmental regulations (Feng et al., 2024; Nan et al., 2022). Geopolitical tensions can exacerbate environmental challenges, especially in developing countries (Ma et al., 2022). In addition, these risks affect environmental policy by disrupting energy security and increasing dependence on fossil fuels (Khan et al., 2023), which hinders investment in renewable energy (Ren et al., 2024). To cope with the negative impact of GPR, some countries are adopting strategies to diversify their energy sources and accelerate the energy transition (Adebayo, 2024). Others favour the implementation of stringent environmental policies to limit the impact of this risk on CO_2 emissions (Luo and Sun, 2024; Ghosh, 2022). While this literature highlights the interdependencies between GPR and countries' strategies to reduce their CO_2 emissions, it remains underexplored. To our knowledge, no work has analysed the effects of these four proposed solutions simultaneously in a unified framework, nor has it examined their interaction with geopolitical risks to assess both their direct and indirect effects on CO_2 emissions in the case of OECD countries. Our study fills this gap by examining the complex dynamics of the effects of geopolitical risks and environmental solutions on CO_2 emissions in OECD countries between 2000 and 2022. These countries were chosen for this study because of their central role in global geopolitical and environmental dynamics. OECD countries assume a significant share of the responsibility for CO_2 emissions, with per capita emissions among the highest in the world. According to the International Energy Agency (IEA, 2023), OECD countries will emit an average of about 8.5 tonnes of CO_2 per capita in 2023, well above the global average of about 4.7 tonnes per capita. In addition, they are responsible for around 37% of global CO_2 emissions, despite having less than 20% of the world's population. Despite their significant carbon footprint, these countries continue to play a leading role in global climate policy efforts and make a significant contribution to global investment in renewable energy. In fact, between 2000 and 2023, the carbon intensity of OECD countries fell by 35% on average, reflecting a transition to less carbon-intensive economies. In addition, the majority of OECD countries have adopted a carbon neutrality target by 2050, reinforcing their commitment to tackling climate change. In addition, between 1990 and 2023, OECD countries have weathered the effects of major geopolitical crises, such as the Gulf War (1990-1991), the terrorist attacks of 11 September 2001, and the far-reaching consequences of the Arab Spring in North Africa and the Middle East. As a result, OECD countries are central to addressing the interrelated global challenges of sustainability and stability.

Our study makes several innovative contributions to the existing literature. First, it examines the moderating role of GPR in the effectiveness of environmental mitigation strategies on CO_2 emissions, providing new insights into the interaction between geopolitical and environmental risks and highlighting their combined impact on sustainable development. Second, and methodologically, the research uses the ARDL-PMG approach to analyse the long- and short-term relationships between variables reflecting environmental solutions: environmental policy stringency, environment-related technologies, renewable energies, and political globalisation and geopolitical risk, taking into account CO_2 emissions. By incorporating factors specific to OECD countries, such as GDP (Ganda, 2019; Dogan et al., 2021; Majeed et al., 2022), and accounting for their heterogeneity, this study strengthens the robustness of its results using advanced techniques such as FMOLS. Third, this research contributes to the literature on geopolitical solutions by proposing policy recommendations to better reconcile geopolitical and environmental issues in a sustainable development approach.

The structure of the paper is as follows: Section 2 reviews the literature and presents the theoretical framework, Section 3 outlines the data and the empirical results, and Section 4 discusses the policy implications and concludes the study.

2. LITERATURE REVIEW

In line with the focus of this research, the literature review is structured around two key axes with a focus on OECD countries: (i) The relationship between CO_2 emissions and four key solutions proposed: environmental policy stringency, environment-related technologies, renewable energy and political globalization; and (ii) the impact of geopolitical risk on CO_2 emissions, including its interactions with these solutions.

2.1. Solution 1: Environmental Policy Stringency

Several studies have examined the impact of EPS on CO_2 emissions. The majority of these studies find a negative relationship between EPS and CO_2 emissions, highlighting the critical role of effective policy design in combating climate change and improving air quality. For OECD countries, studies show a consistent negative impact of EPS on CO_2 emissions. For example, Fatima et al. (2024a) highlight that EPS enhances the benefits of technological innovation in G7 countries, resulting in lower CO_2 emissions, while their second study (Fatima et al., 2024b) of 36 OECD countries suggests that EPS can reduce GHG emissions by around 0.271% to 0.300%. In the same vein, Rehman et al. (2024) find that EPS promote the adoption of renewable energy in 18 OECD countries, thereby reducing dependence on fossil fuels. Consistent with these findings, Frohm et al (2023) report that more stringent policies lead to significant emissions reductions in 30 OECD countries, particularly in fossil fuel-intensive sectors, highlighting the need for faster action to achieve net-zero targets. Ahmed (2020) supports these findings by showing that stricter policies promote green technology and sustainable development in 20 OECD countries. In addition, Mihai et al. (2023) emphasise that market-based instruments with more stringent policies significantly reduce greenhouse gas emissions and increase renewable energy consumption. Daghbagi et al. (2025a) find that institutional quality exerts a significant negative impact on CO_2 emissions in emerging economies in the long run. Their analysis further reveals that institutional quality plays a crucial moderating role by interacting with structural change; the combination of sound institutions and economic transformation creates a synergistic effect that amplifies the reduction of emissions. The study concludes that the emission-mitigating impact of structural change is contingent upon a supportive institutional framework, underscoring the importance of factors like regulatory quality, control of corruption, and policy stability in achieving sustainable development. Finally, Saqib and Dinca (2024) argue that EPS encourage investment in clean energy, leading to lower carbon emissions.

2.2. Solution 2: Environmental-related Technologies

The literature on the impact of ERT on CO_2 emissions highlights both positive results and challenges. For example, Dehdar et al. (2022) analyse 36 OECD countries and find that while industrialisation and fossil fuel use lead to higher CO_2 emissions, urbanisation, environmental patents and environmental taxes are crucial for reducing emissions. They advocate promoting green technologies and increasing environmental taxes to support sustainable growth. In the same vein, Mongo et al (2021) find that while environmental innovations can reduce CO_2 emissions in the long term, they can have a short-term rebound effect that temporarily increases emissions in 15 European countries. In contrast, Alataş (2022) finds a small, statistically insignificant positive effect of environmental technologies on CO_2 emissions in the transport sector of 15 EU countries, suggesting that these technologies alone may not lead to significant reductions. Furthermore, in selected developed and developing countries, economic context and technological capacity significantly influence the relationship between ERT and CO_2 emissions. For example, Dridi et al. (2024) show that in the case of the BRICS plus countries over the period 2000 to 2021, the combined effect of technological innovation and financial development emerges as the most important contributor to environmental quality improvement, surpassing several other factors. Hamrouni, D. et al. (2025) conclude that a nation's technological complexity significantly increases long-term CO_2 emissions in OECD countries, contradicting the common perception that technological advancement inherently benefits the environment. Their multidimensional analysis shows that a 1% rise in the Economic Complexity Index for technology (ECI-Tech) correlates with a 0.05% increase in CO_2 emissions. The authors attribute this positive relationship to the fact that current technological complexity often relies on advanced, but energy-intensive, production processes prevalent in sectors like manufacturing and energy production, and the increased demand for sophisticated products drives up overall production and emissions. Finally, Chen and Lee (2020) emphasise that technological innovation does not reduce CO_2 emissions uniformly, benefiting high-income and high-tech countries while potentially increasing emissions in others, depending on income levels and technological capabilities.

2.3. Solution 3: Renewable Energy Consumption

Renewable energy has been widely studied for its potential to reduce CO_2 emissions in different regions. For example, Acheampong et al. (2022) analysed data from 42 countries (1990-2020) and found that renewable energy consumption effectively reduces greenhouse gas emissions, although the benefits are attenuated under high GPR, indicating the importance of geopolitical stability in maximising the impact of renewable energy. Expanding on the intersection of renewable energy and technology, Ben Jebli et al. (2024) examined the impact of information and communication technologies (ICT) on carbon dioxide emissions in a panel of 84 countries for the years 2009 to 2020. Their findings suggest that ICT and renewable energy consumption contribute significantly to reducing CO_2 emissions, in stark contrast to non-renewable energy, which exacerbates emissions. Similarly, Kahouli et al. (2025) examined the role of structural change in reducing CO_2 emissions in 38 OECD countries between 2000 and 2021. Their study highlights that RE, advances in ICT and structural changes together play a critical role in reducing CO_2 emissions. Similarly, Farooq et al. (2022) further highlight the role of RE in European economies, showing that it significantly reduces CO_2 emissions, especially when combined with technological innovation. Daghbagi et al. (2025b) investigate the effect of renewable energy consumption on CO_2 emissions in G20 countries, finding a significant negative relationship. Their empirical analysis reveals that a 1% increase in renewable energy consumption leads to a 0.04% reduction in CO_2 emissions in the long run. This finding confirms the critical role of transitioning to cleaner energy sources in mitigating carbon emissions. The authors conclude that promoting renewable energy is a vital strategy for G20 nations to enhance environmental quality and achieve climate goals.

Finally, Sultana et al. (2023) confirmed the positive impact of RE in the G7 countries, noting that solar, hydro and nuclear energy significantly reduce emissions, in contrast to the harmful effects of fossil fuel-based electricity.

2.4. Solution 4: Political Globalization

The literature on the impact of political globalisation on CO_2 emissions shows varying effects across regions and economic contexts. In general, several studies highlight that PG helps to reduce emissions by promoting international cooperation and the spread of stronger multilateral environmental agreements. For example, Nan et al. (2022) show that PG increases the effectiveness of RE in reducing emissions in 33 OECD countries, while Chen et al. (2020) show that a 1% increase in PG leads to a 2.4% decrease in emissions growth in 36 OECD countries. Similarly, Paramati et al. (2017) find that PG promotes sustainable practices and reduces emissions in the EU, G20 and OECD countries. In resource-rich countries, Feng et al. (2024) report that PG and foreign direct investment reduce emissions, while GPR and military spending have negative effects. Consistently, Wang et al. (2019) confirm that PG reduces emissions over time in both developed and developing countries. However, there are regional differences. For example, Jahanger (2022) highlights that PG reduces environmental degradation in developing countries, especially when combined with human capital, while Jahanger et al. (2023) find that it reduces emissions in Asia and Africa, but increases them in Latin America and the Caribbean. In Central and Eastern Europe, Destek (2019) finds that PG promotes stricter environmental regulations and reduces pollution.

2.5. Geopolitical Risk and CO_2 Emissions

The impact of geopolitical risk on environmental outcomes, particularly CO_2 emissions, is a global phenomenon that affects countries in different regions and stages of development. Numerous studies have examined this relationship, highlighting different effects in developed and developing countries. For example, Chen et al. (2024) examine the relationship between GPR, globalisation, capital-labour ratio and per capita income on CO_2 emissions inequality using data from 38 countries (1990-2019). Using panel cointegration tests and robust regressions, they find that GPR, the capital-labour ratio and GDP per capita exacerbate emissions inequality, while globalisation mitigates it. Similarly, Ma et al. (2022) analyse the long- and short-term effects of geopolitical risk on CO_2 emissions in eight countries (1990-2020) using the PMG-ARDL model. They find that GPR increases emissions in the long run in both developed and developing countries. Interestingly, the Environmental Kuznets Curve hypothesis holds for developing countries, while the pollution haven hypothesis holds for developed countries. However, in the short run, GPR reduces emissions and neither hypothesis is confirmed. Building on these findings, Kartal and Pata (2023) focus on Russia during the Russia-Ukraine conflict, analysing daily data (2019-2023) using advanced quantile-based methods. Their results show that GPR generally increases emissions across all sectors, although certain quantiles show no causal effect. The authors conclude that geopolitical tensions hinder Russia's carbon neutrality goals. Similarly, Bergougui et al. (2024) use the GMM-PVAR approach to examine 41 countries (1990-2020) and find that GPR significantly increases inequality in carbon emissions, highlighting its detrimental impact on equitable climate action. Husnain et al. (2022) analyse the E7 countries (1990-2015) using the AMG estimator. Their results indicate that GPR reduces CO_2 emissions, suggesting a potential improvement in air quality. However, when ecological footprints are considered, GPR hinders environmental progress. Adding a financial perspective, Kartal et al. (2024) study green bonds, energy prices and GPR using high-frequency data (2020-2023) with a WLMC approach. They find that GPR has the largest impact on emissions in certain periods, outweighing other factors. Finally, Luo et al. (2024) examine the moderating role of EPS in 27 countries (1990-2020). They find that while GPR increases energy-related emissions, stringent environmental policies can mitigate these effects, especially in developing countries. In a recent study, Bakhsh et al. (2024) identify geopolitical risk as a critical barrier to reducing CO_2 emissions and advancing the clean energy transition in OECD economies. Their analysis reveals that geopolitical instability, driven by factors such as armed conflict, terrorism, and international tensions, undermines environmental sustainability through Supply-side effects and Demand-side effects.

Finally, Zhao et al. (2024) examine the impact of geopolitical risk on CO2 emissions in BRICS countries, finding that it directly increases environmental pollution. However, their analysis reveals a significant moderating effect: when combined with green technology innovation, geopolitical risk reduces CO2 emissions. This highlights the crucial role of green innovation in counteracting the environmentally damaging effects of geopolitical instability, suggesting that advancing clean technologies can help mitigate the ecological consequences of international conflicts and tensions.

3. METHODOLOGY AND EMPIRICAL RESULTS

3.1. Model and Data Description

The study examines the determinants of carbon dioxide (CO_2) emissions in 27 OECD countries[1] using annual data from 2000 to 2020. The CO_2 emissions are explained by Gross Domestic Product (GDP), Environmental Policy Stringency (EPS), Environmental-Related Technology (ERT), Renewable Energy (RE), Political Globalisation (PG) and Geopolitical Risk (GPR). The variables are presented in the following Table 1 with their abbreviations, measurement and data source.

Taking into account the specifications of the selected variables, we formulate the CO_2 emission function using the logarithmic transformation as follows:

1 Sample: Belgium, Brazil, Canada, Chile, China, Denmark, Finland, France, Hungary, India, Indonesia, Israel, Italy, Japan, Korea, Mexico, Netherlands, Norway, Poland, Portugal, South Africa, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States.

Table 1: Variables definition

Variables	Description	Unit of Measurement.	Source
CO_2	CO_2 Emission	MM tonnes	EIA (2024)
GDP	Gross Domestic Product	Constant 2015 USD	WDI (2024)
EPS	Environmental Policy Stringency	Index	EIA (2024)
ERT	Environmental- related technology	Index	OECD (2024)
RE	Renewable Energy	QBTU	EIA (2024)
PG	Political Globalization	Index	KOF Swiss Economic institute, (2024)
GPR	Geopolitical Risk	Index	Policyuncertainty.com (2024)

Table 2: Descriptive statistics

Statistics	$LNCO_2$	LNGDP	LNEPS	LNERT	LNRE	LNPG	LNGPR
Mean	5.570	27.33494	0.962011	1.143250	0.521215	4.467583	0.939425
Median	5.781	27.26591	0.980829	1.934484	0.300103	4.498322	0.685326
Maximum	9.291	30.63356	1.773067	4.755683	2.995926	4.585593	3.973993
Minimum	3.355	24.99700	0.000000	−6.381482	−0.184180	3.623676	0.065911
Std. Dev.	1.354270	1.159915	0.454125	2.408863	0.587362	0.113997	0.754023
Skewness	0.461551	0.559309	−0.361456	−0.865459	1.714133	−3.084213	1.596672
Kurtosis	2.977949	3.163630	2.020231	2.927972	5.608458	18.37077	5.347441
Jarque-Bera	29.73450	44.57313	51.70387	104.6692	647.1775	9566.559	547.8139
Probability	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Observations	837	837	837	837	837	837	837

Table 3: The correlation matrix

	$LNCO_2$	LNGDP	LNEPS	LNERT	LNRE	LNPG	LNGPR
$LNCO_2$	1						
LNGDP	0.844***	1					
LNEPS	−0.142***	0.184***	1				
LNERT	−0.167***	0.189***	0.720***	1			
LNRE	−0.605***	0.711***	0.032	0.046*	1		
LNPG	−0.077***	0.200***	0.609	05054***	0.111***	1	
LNGPR	0.703**	0.773***	0.033***	0.164***	0.519**	0.128***	1

***, **Significance level at 1% and 5%

$$LNCO_{2it} = \beta_0 + \beta_1 LNGDP_{it} + \beta_2 LNEPS_{it} + \beta_3 LNERT_{it} + \beta_4 LNRE_{it} + \beta_5 LNPG_{it} + \beta_6 LNGPR_{it} + u_{it} \quad (1)$$

The coefficients $\beta_i, i = 1,\ldots,6$ represent the parameters associated with the independent variables and u_{it} implies the error term.

Equation (1) is then extended by introducing interaction terms between the geopolitical risk index (GPR) and four explanatory variables. Specifically, interactions are introduced between the geopolitical risk index and Environmental Policy Stringency (LNGPR×LNEPS), the Environmental Technology Index (LNGPR×LNERT), the Political Globalisation Index (LNGPR×LNRE), and Renewable Energy (LNGPR×LNPG). The following equations present the different specifications with the interaction terms:

$$LNCO_{2it} = \beta_0 + \beta_1 LNGDP_{it} + \beta_2 LNEPS_{it} + \beta_3 LNERT_{it} + \beta_4 LNRE_{it} + \beta_5 LNPG_{it} + \delta_1 (LNGPR_{it} \times LNEPS_{it}) + v_{it} \quad (2)$$

$$LNCO_{2it} = \beta_0 + \beta_1 LNGDP_{it} + \beta_2 LNEPS_{it} + \beta_3 LNERT_{it} + \beta_4 LNRE_{it} + \beta_5 LNPGit + \delta_2 (LNGPR_{it} \times LNERT_{it}) + v_{it} \quad (3)$$

$$LNCO_{2it} = \beta_0 + \beta_1 LNGDP_{it} + \beta_2 LNEPS_{it} + \beta_3 LNERT_{it} + \beta_4 LNRE_{it} + \beta_5 LNPG_{it} + \delta_3 (LNGPR_{it} \times LNRE_{it}) + v_{it} \quad (4)$$

$$LNCO_{2it} = \beta_0 + \beta_1 LNGDP_{it} + \beta_2 LNEPS_{it} + \beta_3 LNERT_{it} + \beta_4 LNRE_{it} + \beta_5 LNPG_{it} + \delta_4 (LNGPR_{it} \times LNPG_{it}) + v_{it} \quad (5)$$

δ_j; j =1,…,4 represent the parameters associated with the interaction terms ($LNGPR_{it} \times LNEPS_{it}$),($LNGPR_{it} \times LNERT_{it}$), ($LNGPR_{it} \times LNRE_{it}$),and ($LNGPR_{it} \times LNPG_{it}$), used in equations (2) to (5), and v_{it} implies error term.

These interactions make it possible to examine not only the direct effects of the independent variables on CO_2 emissions, but also their combined effects, which can provide a better understanding of the underlying mechanisms. Estimates of the coefficients associated with these interaction terms are interpreted to assess the impact of the complex relationships between the explanatory variables and CO_2 emissions.

In the following, we present the results of our analysis, with the tests carried out to validate the estimation of our models, as well as the estimation results and their respective interpretations

3.2. Empirical Results

3.2.1. Descriptive statistics

The descriptive statistics in Table 2 present the basic characteristics of the variables studied, enabling the distribution of the data and the main trends to be analyzed.

The results in Table 2 show that CO_2 emissions have a mean of 5.570, with a slightly positive skewness (0.461), indicating a distribution slightly skewed towards lower values. Gross

Domestic Product (GDP), measured in constant 2015 USD, has an average of 27,334.94 USD and a moderate skewness (0.559), indicating a relatively balanced distribution, but with a slight bias towards higher values. The share of renewable energy has a mean of 0.939 and a strong positive skewness (1.596), indicating a concentration of values around low renewable energy rates, although there are a few high values. The geopolitical risk index shows a strong negative skewness (−3.084), indicating a distribution concentrated around low risks with a few extreme values. The index of environmental policy stringency shows a small negative skewness (−0.361) and low dispersion, while the index of environmental- related technology shows significant variation (standard deviation of 2.41) and a negative skewness, indicating an uneven adoption of green technologies. Finally, the political globalisation index is generally symmetric, with the mean close to the median. The normality tests, represented by the Jarque-Bera values, show that all the variables have significantly non-normal distributions, indicating the presence of extreme values or significant skewness in the data.

The correlation matrix (Table 3) reveals several interesting relationships between the variables studied. First, a strong positive correlation is observed between CO_2 emissions and GDP (0.844), suggesting that an increase in GDP is generally associated with higher CO_2 emissions, probably due to greater energy consumption. In addition, renewable energy and GDP are also positively correlated (0.711), suggesting that countries with higher GDP tend to invest more in renewable energy. On the other hand, CO_2 emissions and environmental policy stringency (EPS) show a low negative correlation (−0.142), suggesting that countries with higher CO_2 emissions are not necessarily those with stricter environmental policies. Regarding the adoption of environmental-related technologies (ERT), there is a strong positive correlation with the stringency of environmental policies (0.720), suggesting that strict policies encourage innovation in this area. Furthermore, the index of geopolitical risk (GPR) and the index of political globalization (PG) show moderate correlations with other variables, suggesting that geopolitical risk and political globalization are often linked to economic and environmental trends, although the relationships remain relatively weak. Finally, several variables show weak correlations, indicating complex but unsystematic links between them, such as between renewable energy and the political globalization index (0.111) or between geopolitical risks and environmental-related technologies (0.164). These results highlight the multiple and sometimes counterintuitive dynamics between economic, environmental and geopolitical factors. Overall, the VIFs are all relatively low to moderate (with no VIF exceeding 5), suggesting that there is no excessive multicollinearity in the modelling (Table 4).

Table 4: VIF test

Variable	Vif	1/Vif
LNGDP	3.95	0.253
LNEPS	2.61	0.383
LNGPR	2.60	0.385
LNERT	2.17	0.460
LNRE	2.09	0.478
LNPG	1.64	0.611

Table 5: Cross-section dependence tests

Test	Statistic	d.f.	Prob.
Pearson LM Normal	2.154		0.031
Pearson CD Normal	1.781		0.074
Friedman Chi-square	42.239	30	0.068

3.2.2. Cross-section dependence tests

The results of the Pearson and Friedman cross-section dependence tests, presented in Table 5, reject the hypothesis of cross-sectional independence of our model. It is essential to use second-generation unit root tests, such as CIPS and the CADF tests by Pesaran (2007), which allow cross-sectional dependence to be taken into account. Thus, unit root tests were carried out to verify the stationarity of the variable time series, which is crucial to ensure the robustness of the analyses.

3.2.3. Unit root tests

The results of the stationarity test in Table 6 (CIPS and CADF) show the order of integration according to the significance levels of the different variables.

Table 6: The panel unit root tests

Variable	CIPS		CADF		Variable	CIPS		CADF		Verdict
	Intercept	Trend	Intercept	Trend		Intercept	Trend	Intercept	Trend	
$LNCO_2$	−1.977	−2.787	0.167 (0.566)	−0.534 (0.297)	$DLNCO_2$	−5.406***	−5.489***	−10.682*** (0.000)	−.288** (0.000)	I (1)
LNGDP	−2.230	−2.342	−1.651** (0.049)	0.608 (0.728)	DLGDP	−3.660***	−3.724***	−6.914*** (0.000)	−4.317 (0.000)	I (1)
LNEPS	−2.963***	−3.055***	−2.180 (0.015)	3.390 (1.000)	DLNEPS	−5.350***	−5.447***	−13.280*** (0.000)	−1.804** (0.036)	I (0)
LNERT	−3.542***	−3.723***	−6.655*** (0.000)	−1.573* (0.058)	DLNERT	−5.548	−5.762***	−15.242*** (0.000)	−11.196*** (0.000)	I (0)
LNRE	−2.704***	−3.253***	−2.204** (0.014)	−2.502 (0.006)	DLNRE	−5.508***	−5.714***	−13.543 (0.00)	−11.420 (0.000)	I (0)
LNPG	−3.730***	−3.969***	−7.697 (0.000)	−7.012*** (0.000)	DLNPG	−5.570***	−5.650***	−14.427*** (0.000)	−13.518*** (0.000)	I (0)
LNGPR	−3.269***	−3.742***	−5.418*** (0.000)	−4.521 (0.00)	DLNGPR	−6.018***	−6.118***	−15.917*** (0.000)	−13.686*** (0.000)	I (0)

***, **, and * are statistical significance at the 1%, 5%, and 10% levels, respectively. The critical values associated with the 1%, 5%, and 10% thresholds for the CIPS statistics without trend are−2.08, −2.16, −2.3, respectively, while the critical values for the specification with trend are−2.58, −2.65, −2.678. For the CADF test, we use the Z-bar statistic, and the associated P values are indicated in parentheses

Table 7: Model estimations

Long run					
Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
LNGDP	1.749***	0.388***	1.087***	1.963***	1.761***
LNEPS	−0.645***	−0.071***	−0.133**	−0.539***	−0.648***
LNERT	−0.090***	0.072***	−0.196***	−0.122**	−0.091***
LNRE	−1.289***	−0.202***	−1.837***	−3.536***	−1.300***
LNPG	−0.423***	0.244***	−0.440	−0.919	−0.448***
LNGPR	0.065**				
LNGPR×LNEPS		0.066***			
LNGPR×LNERT			0.042***		
LNGPR×LNRE				0.788***	
LNGPR×LNPG					0.015**
Short run					
Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
COINTEQ01	−0.072**	0.142**	−0.068***	−0.046**	−0.071***
D(LNGDP)	1.098***	1.075***	0.933***	0.999***	1.097***
D(LNEPS)	0.027	0.010*	−0.011	−0.011	0.026
D(LNERT)	0.029**	0.037*	0.022*	0.018*	0.029**
D(LNRE)	−0.319	−0.288*	−0.373**	−0.319*	−0.319
D(LNPG)	−0.416	−0.679*	−0.158	−0.248	−0.422
D(LNGPR)	0.003				
D(LNGPR×LNEPSI)		0.032**			
D(LNGPR×LNERT)			−0.003**		
D(LNGPR×LNRE)				−0.023	
D(LNGPR×LNPG)					0.0007

***, **, and * significance level at the 1%, 5%, and 10% level respectively

The results of the unit root tests (CIPS and CADF) indicate that most of the variables are stationary in their level form, with the exception of CO_2 emissions and GDP. More specifically, CO_2 and GDP are integrated of order 1 (I (1)), which means that they are non-stationary in their level form, but become stationary after first differencing. On the other hand, the series RE, GPR, EPS, ERT and GPO are stationary at level (I(0)), which means that they do not require differencing to become stationary. These results suggest that the data are suitable for further econometric analysis, such as the ARDL panel model.

3.2.4. The PMGARDL estimates

We employed the PMG-ARDL approach (Pesaran et al., 1999) to estimate our models. Table 7 presents the estimation results and a detailed interpretation of the key findings. Estimations reveal important results for the analysis of the determinants of CO_2 emissions, especially in the long term. First, the results show that the long-run equilibrium adjustment term is negative and significant in all models, indicating a rapid adjustment towards the long-run equilibrium. Second, in terms of coefficients, we find that Gross Domestic Product (GDP) has a positive and significant impact in all models, with coefficients ranging from 1.749 (Model 1) to 1.761 (Model 5), suggesting that an increase in GDP leads to rise CO_2 emissions. This result is consistent with other studies that also found a positive effect of economic growth on CO_2 emissions. (Ganda, 2019; Majeed et al., 2022; Dogan et al., 2021; Ouerghi, and Hasni, 2025; Daghbagi, 2025; Zohra, 2025).

The analysis of the direct impact of the four variables reflecting the four mitigation strategies and the direct impact of geopolitical risk is as follows. The Environmental Policy Stringency (EPS) index has a significant negative effect in all models, with coefficients ranging from −0.648 in model 5 to −0.645 in model 1. This suggests that stringent environmental policies are associated with a reduction in CO_2 emissions. These results are supported by several studies, including Ahmed (2020), Fatima et al. (2024) and Rehman et al. (2024), which confirm the role of EPS in reducing emissions in G7 and OECD countries. Similarly, the Environmental Related Technology (ERT) index also shows a negative effect, although this effect is more moderate, with coefficients ranging from −0.091 in model 5 to −0.090 in model 1. This suggests that advances in environmental technologies contribute to emission reductions, as highlighted in studies by Chen and Lee (2020), Hussain and Dogan (2021) and Mongo et al. (2021) and Hamrouni (2025). Renewable energy (RE) also shows a consistently negative and significant effect in all models, confirming that investments in renewable energy are effective in reducing CO_2 emissions, in line with the findings of Kahouli et al. (2025), Ben Jebli et al. (2024) and Sultana et al. (2023), Daghbagi et al. (2025c) and Umar Farooq et al. (2023). Moreover, the effect of political globalisation (PG) on CO_2 emissions, which is negative and significant in four out of five models, generally suggests that increased participation in PG contributes to lower emissions. This result is consistent with the work of Nan et al. (2022) on 33 OECD countries, as well as the work of Paramati et al. (2017) on the European Union, the G20 and OECD countries. However, these conclusions contrast with those of Jahanger et al. (2023), who find an opposite effect in Latin America and the Caribbean. Finally, the Geopolitical Risk (GPR) variable shows a positive effect in Model 1, with a coefficient of 0.065, implying that increased geopolitical risk is associated with a increase in CO_2 emissions. This result is consistent with studies by Bergougui et al. (2024), Kartal and Pata (2023) and Ma et al. (2022), which highlight the role of geopolitical risk in driving long-term emissions, although it contradicts the findings of Husnain et al. (2022) for E7 countries, where geopolitical risk is found to reduce emissions.

Table 8: Model estimation using FMOLS

Variable	FMOLS				
	Model 1	Model 2	Model 3	Model 4	Model 5
LNGDP	0.394***	0.532***	0.309***	0.612***	0.401***
LNEPS	0.008	−0.027**	0.324***	−0.092***	0.069***
LNERT	−0.291***	−0.422***	−0.463***	−0.594***	−0.405***
LNRE	−0.901***	−0.735***	−0.821***	−0.841***	−0.861***
LNPG	0.537***	0.229***	0.429***	0.270***	0.435***
LNGPR	0.484***				
LNGPR×LNEPS		0.088***			
LNGPR×LNERT			0.418***		
LNGPR×LNRE				0.213***	
LNGPR×LNPG					0.352***
Adjusted R-squared	0.904	0.877	0.499	0.800	0.837

***, **, and * show significance at the 1%, 5%, and 10% level respectively

The interaction terms highlight the importance of combined effects of geopolitical risk with other variables. For example, in Model 2, The interaction between geopolitical risk and environmental policy stringency (LNGPR×LNEPS) has a positive and significant coefficient, indicating that geopolitical risk completely reverses the positive effect of environmental policy stringency, increasing CO_2 emissions rather than reducing them. In model 3, the interaction between geopolitical risk and environmental technology (LNGPR×LNERT) has a moderate positive effect on CO_2 emissions of 0.042, suggesting that the interaction with geopolitical risk reverses the direct effect of technological progress by increasing emissions. Similarly, Model 4 presents a positive coefficient for the interaction between geopolitical risk and renewable energy (LNGPR×LNRE), indicating that geopolitical risk, when interacting with renewable energy, leads to a significant increase in CO_2 emissions. Finally, Model 4 shows a positive coefficient on the interaction (LNGPR × LNPG), indicating that the combined effect of geopolitical risk and political globalisation leads to an increase in emissions. To test the robustness of our results, we also applied the Fully Modified Ordinary Least Squares (FMOLS) method developed by Stock and Watson (1993), Phillips (1995). FMOLS is particularly useful for obtaining reliable long-run estimates in regression models with co-integrated variables. The results of this test are presented in Table 8.

The robustness test results in long- term using the FMOLS method indicate that Gross Domestic Product (GDP) has a positive and significant effect on CO_2 emissions, suggesting that larger economies tend to produce more pollution. Environmental policies (EPS) exhibit mixed effects: in some models, they appear to reduce emissions, while in others, they may paradoxically increase them. The impact of ERT and renewable energy (RE) is consistently negative, indicating that greater adoption of these technologies and renewable energy sources are associated with a reduction in CO_2 emissions. As for political globalization (PG), its effect on emissions is positive, implying that greater political integration may lead to higher emissions. Finally, geopolitical risk (GPR) also shows a positive impact on CO_2 emissions, suggesting that during periods of geopolitical instability, countries may prioritize more pollute economic growth strategies. The results for the interaction terms remained consistent. In more detail, the interactions between geopolitical risk and environmental policy stringency (LNGPR×LNEPS), environmental technology (LNGPR×LNERT), renewable energy (LNGPR×LNRE) and political globalisation (LNGPR×LNPG) all show positive and significant effects. This suggests that geopolitical risk not only exacerbates CO_2 emissions, but also, when combined with these factors, negates the direct emission-reducing effects of these factors, resulting in higher emissions. These results are consistent with those derived from the PMG-ARDL model, reinforcing the robustness and consistency of the results across different econometric approaches.

4. CONCLUSION AND POLICY RECOMMENDATIONS

This study comes at a time when concerns about environmental and geopolitical risks are at the forefront of international discussions. The aim of this study was therefore to analyse the impact of environmental policies and geopolitical risks on CO_2 emissions in OECD countries, using data for the period 2000-2020. Although many studies have examined the determinants of CO_2 emissions, few have simultaneously included geopolitical risk and its interactions with environmental and economic variables in their analysis. To the best of our knowledge, this article stands out for its in-depth exploration of the interactions between geopolitical risk and specific strategies, such as environmental policy stringency, environment-related technologies, renewable energy and political globalisation. In addition, we have used an innovative methodology that combines the ARDL-PMG approach to assess short- and long-term effects and the FMOLS methods to ensure the robustness and validity of the results. This approach fills an important gap in the literature by providing a more nuanced understanding of the mechanisms by which geopolitical risk can moderate the effectiveness of environmental policies.

Our study shows that EPS, ERT, RE and PG significantly reduce CO_2 emissions. However, GPR not only directly increases emissions, but also interacts negatively with these solutions, undermining their effectiveness and in some cases reversing their benefits. These findings are consistent with the World

Economic Forum's Global Risks 2024 report, which emphasises localised strategies, technological disruption, collective action and cross-border coordination. While confirming the importance of stringent regulations, R&D environmental investment, renewable energy deployment and global cooperation, the study underscores the need to address GPR to improve the effectiveness of climate change policies. To address this, specific measures are required for each strategy to mitigate these adverse effects. First, for stringent environmental regulations, often compromised by geopolitical instability, it is imperative to strengthen national resilience by adapting policies to local contexts and incorporating flexibility clauses to manage crises. Additionally, governments should implement economic stabilisation mechanisms, such as emergency funds to support businesses, and promote international agreements to prevent carbon leakage into less regulated countries. Continuous monitoring of GPR is also essential to ensure that policies remain effective in real time. Second, regarding environmental R&D investments, frequently disrupted by conflict, it is critical to secure funding through protected, dedicated funds and diversify sources to reduce vulnerabilities. Strengthening international cooperation to share innovation costs and risks is equally important. Moreover, programmes to safeguard R&D infrastructure, such as creating special economic zones or providing international guarantees, can help ensure project continuity during crises. Third, for renewable energy, whose deployment faces delays due to geopolitical supply chain disruptions, diversifying sources of critical raw materials and establishing strategic stockpiles are essential. Governments should also invest in resilient and decentralised infrastructure to reduce reliance on geopolitically unstable regions. Furthermore, international agreements to stabilise renewable energy markets and promote equitable access to clean technologies are vital for countering the effects of conflict. Finally, in the context of PG, often weakened by geopolitical tensions, bolstering international institutions and fostering proactive climate diplomacy are crucial to maintaining cooperation during crises. OECD countries must lead efforts to form multilateral coalitions focused on shared climate objectives, including mediation mechanisms to resolve resource-related disputes. Strengthening transparency and trust among nations through regular climate progress reports and verifiable commitments will sustain collaboration despite geopolitical risks. These targeted actions will ensure that the strategies for reducing emissions remain effective, even in the face of significant geopolitical challenges.

Ultimately, this study highlights the need to integrate geopolitical dynamics into the design of climate policies. The results underline that the success of environmental policies depends on effective coordination between national policies and enhanced international cooperation. Finally, future research could include a sectoral analysis of impacts, an examination of the interactions between geopolitical risks and other environmental solutions, such as green finance, as well as an extension of the analysis to emerging economies or a global study covering all countries to provide a more complete perspective.

5. FUNDING

This work was supported and funded by the Deanship of Scientific Research at Imam Mohammad Ibn Saud Islamic University (IMSIU) (grant number IMSIU-DDRSP2502).

REFERENCES

Acheampong, A.O. (2022), The impact of de facto globalization on carbon emissions: Evidence from Ghana. International Economics, 170, 156-173.

Adebayo, T.S. (2024), Do uncertainties moderate the influence of renewable energy consumption on electric power CO_2 emissions? A new policy insights. International Journal of Sustainable Development and World Ecology, 31(3), 314-329.

Ahmed, K. (2020), Environmental policy stringency, related technological change and emissions inventory in 20 OECD countries. Journal of Environmental Management, 274, 111209.

Ahmed, N., Areche, F.O., Nieto, D.D.C., Borda, R.F.C., Gonzales, B.C., Senkus, P., Siemiński, P., Skrzypek, A. (2022), Nexus between cyclical innovation in green technologies and CO_2 emissions in nordic countries: Consent toward environmental sustainability. Sustainability, 14(18), 11768.

Alataş, S. (2022), Do environmental technologies help to reduce transport sector CO_2 emissions? Evidence from the EU15 countries. Research in Transportation Economics, 91, 101047.

Bakhsh, S., Zhang, W., Ali, K., Anas, M. (2024), Energy transition and environmental stability prospects for OECD economies: The prominence role of environmental governance, and economic complexity: Does the geopolitical risk matter? Journal of Environmental Management, 354, 120358.

Ben Jebli, M., Hasni, R., Jaouadi, I. (2024), Does ICT influence carbon emissions in the context of universal connectivity: A global perspective? Environmental Science and Pollution Research, 31(6), 9535-9549.

Bergougui, B., Doğan, B., Ghosh, S., Ayad, H. (2024), Impact of environmental technology, economic complexity, and geopolitical risk on carbon emission inequality in developed and developing countries: Evidence from a PVAR-GMM approach. Environment Development and Sustainability, 2024, 1-31.

Cengiz, O., Manga, M. (2022), Is there any relationship between geopolitical risk and climate change? Ekonomski Vjesnik Econviews Review of Contemporary Business Entrepreneurship and Economic Issues, 35(1), 99-112.

Chen, L., Gozgor, G., Lau, C.K.M., Mahalik, M.K., Rather, K.N., Soliman, A.M. (2024), The impact of geopolitical risk on CO_2 emissions inequality: Evidence from 38 developed and developing economies. Journal of Environmental Management, 349, 119345.

Chen, T., Gozgor, G., Koo, C.K., Lau, C.K.M. (2020), Does international cooperation affect CO_2 emissions? Evidence from OECD countries. Environmental Science and Pollution Research, 27, 8548-8556.

Chen, Y., Lee, C.C. (2020), Does technological innovation reduce CO_2 emissions? Cross-country evidence. Journal of Cleaner Production, 263, 121550.

Daghbagi, H. (2025), Globalisation de facto, Globalisation de jure and CO_2 emissions in GCC countries: Insights from a panel PMG-ARDL approach. Climatic Change, 178(7), 1-22.

Daghbagi, H., Hasni, R., Imen, O. (2025a), The moderating effect of institutional quality on the relationship between structural change and CO_2 emissions in emerging economies. Environmental and Sustainability Indicators, 2025, 100817.

Daghbagi, H., Hasni, R., Ben Jebli, M. (2025b), The assessment of economic complexity and financial development on environmental quality: Evidence for panel cointegration approach. Air Quality Atmosphere and Health, 2025, 1-16.

Daghbagi, H., Ouerghi, I., Hasni, R. (2025c), The role of productive capacity pillars in CO_2 emissions: How does their interaction matter in the MENA region? International Journal of Energy Economics and Policy, 15(4), 34.

Dehdar, F., Silva, N., Fuinhas, J.A., Koengkan, M., Nazeer, N. (2022), The impact of technology and government policies on OECD carbon dioxide emissions. Energies, 15(22), 8486.

Destek, M.A. (2020), Investigation on the role of economic, social, and political globalization on environment: Evidence from CEECs. Environmental Science and Pollution Research, 27(27), 33601-33614.

Doğan, B., Driha, O.M., Balsalobre Lorente, D., Shahzad, U. (2021), The mitigating effects of economic complexity and renewable energy on carbon emissions in developed countries. Sustainable Development, 29(1), 1-12.

Dridi, D., Hasni, R., KahiA, M. (2024), Environmental degradation and financial development nexus in BRICS PLUS Countries: Do financial development drivers make a difference? Journal of the Knowledge Economy, 16, 10222-10254.

Energy Information Administration, EIA. (2024), Available from: https://www.eia.gov/international/data/world [Last accessed on 2024 Oct 20].

Farooq, S., Ozturk, I., Majeed, M.T., Akram, R. (2022), Globalization and CO_2 emissions in the presence of EKC: A global panel data analysis. Gondwana Research, 106, 367-378.

Fatima, N., Xuhua, H., Alnafisah, H., Akhtar, M.R. (2024a), Synergy for climate actions in G7 countries: Unraveling the role of environmental policy stringency between technological innovation and CO_2 emission interplay with DOLS, FMOLS and MMQR approaches. Energy Reports, 12, 1344-1359.

Fatima, N., Xuhua, H., Alnafisah, H., Zeast, S., Akhtar, M.R. (2024b), Enhancing climate action in OECD countries: The role of environmental policy stringency for energy transitioning to a sustainable environment. Environmental Sciences Europe, 36(1), 157.

Feng, Y., Sabir, S.A., Quddus, A., Wang, J., Abbas, S. (2024), Do the grey clouds of geopolitical risk and political globalization exacerbate environmental degradation? Evidence from resource-rich countries. Resources Policy, 89, 104533.

Friedman, M. (1937), The use of ranks to avoid the assumption of normality implicit in the analysis of variance. Journal of the American Statistical Association, 32(200), 675-701.

Frohm, E., D'Arcangelo, F.M., Kruse, T., Pisu, M., Sila, U. (2023), Environmental policy stringency and CO_2 emissions: Evidence from cross-country sector-level data (No. 1773). OECD Publishing.

Ganda, F. (2019), The impact of innovation and technology investments on carbon emissions in selected organisation for economic Co-operation and development countries. Journal of Cleaner Production, 217, 469-483.

Ghosh, S. (2022), Renewable energy and CO_2 emissions: The economics and geopolitical implications, experiences from the BRICS nations. International Journal of Energy Sector Management, 16(6), 1064-1090.

Hamrouni, D. (2025), Mitigating trade-related CO_2 emissions: The role of renewable energy, environmental technologies, and policy stringency in BRICS Countries: A PMG-ARDL analysis. International Journal of Energy Economics and Policy, 15(4), 214.

Hamrouni, D., Hasni, R., Ben Jebli, M. (2025), The impact of economic complexity in trade, technology, and research on CO_2 emissions: Evidence from OECD countries. Environmental Modeling and Assessment, 2025, 1-18.

Husnain, M.I.U., Syed, Q.R., Bashir, A., Khan, M.A. (2022), Do geopolitical risk and energy consumption contribute to environmental degradation? Evidence from E7 countries. Environmental Science and Pollution Research, 29(27), 41640-41652.

Hussain, M., Dogan, E. (2021), The role of institutional quality and environment-related technologies in environmental degradation for BRICS. Journal of Cleaner Production, 304, 127059.

Jahanger, A. (2022), Impact of globalization on CO_2 emissions based on EKC hypothesis in developing world: The moderating role of human capital. Environmental Science and Pollution Research, 29(14), 20731-20751.

Jahanger, A., Yang, B., Huang, W.C., Murshed, M., Usman, M., Radulescu, M. (2023), Dynamic linkages between globalization, human capital, and carbon dioxide emissions: Empirical evidence from developing economies. Environment Development and Sustainability, 25(9), 9307-9335.

Kahouli, Z., Hasni, R., Jebli, M.B. (2025), Analyzing the influence of structural changes on CO_2 emissions in OECD countries: Employing panel cointegration techniques. International Journal of Renewable Energy Development, 14(1), 168-179.

Kartal, M.T., Pata, U.K. (2023), The function of geopolitical risk on carbon neutrality under the shadow of Russia-Ukraine conflict: Evidence from Russia's sectoral CO_2 emissions by high-frequency data and quantile-based methods. Journal of Sustainable Development Issues, 1(1), 1-12.

Kartal, M.T., Taşkın, D., Kılıç Depren, S. (2024), Dynamic relationship between green bonds, energy prices, geopolitical risk, and disaggregated level CO_2 emissions: Evidence from the globe by novel WLMC approach. Air Quality Atmosphere and Health, 17, 1763-1775.

Khan, K., Khurshid, A., Cifuentes-Faura, J. (2023), Is geopolitics a new risk to environmental policy in the European union? Journal of Environmental Management, 345, 118868.

KOF Swiss Economic Institute. (2024), Available from: https://www.kof.ethz.ch/en [Last accessed on 2024 Oct 20].

Kwilinski, A., Lyulyov, O., Pimonenko, T. (2024), Reducing transport sector CO_2 emissions patterns: Environmental technologies and renewable energy. Journal of Open Innovation Technology Market and Complexity, 10(1), 100217.

Kyoto Protocol. (1997). Available from: https://unfccc.int/process-and-meetings/the-kyoto-protocol

Luo, H., Sun, Y. (2024), Effects of geopolitical risk on environmental sustainability and the moderating role of environmental policy stringency. Scientific Reports, 14(1), 10747.

Ma, W., Nasriddinov, F., Haseeb, M., Ray, S., Kamal, M., Khalid, N., Ur Rehman, M. (2022), Revisiting the impact of energy consumption, foreign direct investment, and geopolitical risk on CO_2 emissions: Comparing developed and developing countries. Frontiers in Environmental Science, 10, 985384.

Majeed, M.T., Mazhar, M., Samreen, I., Tauqir, A. (2022), Economic complexities and environmental degradation: Evidence from OECD countries. Environment, Development and Sustainability, 24(4), 5846-5866.

Mehmood, U. (2021), Globalization-driven CO_2 emissions in Singapore: An application of ARDL approach. Environmental Science and Pollution Research, 28(9), 11317-11322.

Mihai, D.M., Doran, M.D., Puiu, S., Doran, N.M., Jianu, E., Cojocaru, T.M. (2023), Managing environmental policy stringency to ensure sustainable development in OECD Countries. Sustainability, 15(21), 15427.

Mongo, M., Belaïd, F., Ramdani, B. (2021), The effects of environmental innovations on CO_2 emissions: Empirical evidence from Europe.

Environmental Science and Policy, 118, 1-9.

Muhammad, B., Khan, M.K. (2021), Foreign direct investment inflow, economic growth, energy consumption, globalization, and carbon dioxide emission around the world. Environmental Science and Pollution Research, 28(39), 55643-55654.

Nan, S., Huang, J., Wu, J., Li, C. (2022), Does globalization change the renewable energy consumption and CO_2 emissions nexus for OECD countries? New evidence based on the nonlinear PSTR model. Energy Strategy Reviews, 44, 100995.

OECD. (2024), Available from: https://www.oecd.org [Last accessed on 2024 Oct 20].

Ouerghi, I., Hasni, R. (2025), Examining the influence of global value chains and economic complexity on carbon emissions: Insights from top ten emitters. Development and Sustainability in Economics and Finance, 5, 100039.

Paramati, S.R., Apergis, N., Ummalla, M. (2017), Financing clean energy projects through domestic and foreign capital: The role of political cooperation among the EU, the G20 and OECD countries. Energy Economics, 61, 62-71.

Paris Agreement (2015). United Nations Framework Convention on Climate Change. (2015, December 12). Paris Agreement. Paris, France. Available from: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

Pesaran, M.H. (2007), A simple panel unit root test in the presence of cross-section dependence. Journal of Applied Econometrics, 22(2), 265-312.

Pesaran, M.H. (2015), Testing weak cross-sectional dependence in large panels. Econometric Reviews, 34(6-10), 1089-1117.

Pesaran, M.H. (2021), General diagnostic tests for cross-sectional dependence in panels. Empirical Economics, 60(1), 13-50.

Pesaran, M.H., Shin, Y., Smith, R.P. (1999), Pooled mean group estimation of dynamic heterogeneous panels. Journal of the American Statistical Association, 94(446), 621-634.

Phillips, P.C. (1995), Fully modified least squares and vector autoregression. Econometrica Journal of the Econometric Society, 63, 1023-1078.

Policy Uncertainty. (2024), Available from: https://policyuncertainty.com [Last accessed on 2024 Oct 10].

Rehman, M.A., Hasan, M., Pata, U.K., Chen, X.H., Kontoleon, A. (2024), Exploring the Nexus of technology, environmental policy stringency, and political globalization: Pathways to achieving sustainability. Energy Economics, 2024, 107979.

Ren, X., Yang, W., Jin, Y. (2024), Geopolitical risk and renewable energy consumption: Evidence from a spatial convergence perspective. Energy Economics, 131, 107384.

Saqib, N., Dincă, G. (2024), Exploring the asymmetric impact of economic complexity, FDI, and green technology on carbon emissions: Policy stringency for clean-energy investing countries. Geoscience Frontiers, 15(4), 101671.

Sohag, K., Husain, S., Soytas, U. (2024), Environmental policy stringency and ecological footprint linkage: Mitigation measures of renewable energy and innovation. Energy Economics, 2024, 107721.

Stock, J.H., Watson, M.W. (1993), A simple estimator of cointegrating vectors in higher order integrated systems. Econometrica Journal of the Econometric Society, 1993, 783-820.

Sultana, T., Hossain, M.S., Voumik, L.C., Raihan, A. (2023), Does globalization escalate the carbon emissions? Empirical evidence from selected next-11 countries. Energy Reports, 10, 86-98.

Umar Farooq, M., Amin, A., Peng, S., Işık, C., Aqdas, R., Akbar, M., Sabahat, G., Ongan, S. (2023), Role of innovations to mitigate CO_2e: Theory and evidence for European economies. Sustainability, 15(9), 7618.

UNFCCC. (1992). United Nations Framework Convention on Climate Change. Availble from: https://unfccc.int/resource/docs/convkp/conveng.pdf

Wang, Y., Zhou, T., Chen, H., Rong, Z. (2019), Environmental homogenization or heterogenization? The effects of globalization on carbon dioxide emissions, 1970-2014. Sustainability, 11(10), 2752.

World Development Indicators, WDI. (2024), Washington DC, USA: The World Bank. Available from: https://data.worldbank.org/data-catalog/world-development-indicators [Last accessed on 2024 Oct 20]

World Economic Forum. WEF. (2024), The Global Risks Report 2024. Available from: https://www.weforum.org/publications/global-risks-report-2024

Zhao, Y., Wang, W., Liang, Z., Luo, P. (2024), Racing towards zero carbon: Unraveling the interplay between natural resource rents, green innovation, geopolitical risk and environmental pollution in BRICS countries. Resources Policy, 88, 104379.

Zohra, K. (2025), Exploring the relationship between ICT and CO_2 emissions in MENA countries: A panel ARDL-PMG analysis. Nature Environment and Pollution Technology, 24(4), 1764.