Exploring the Nexus of technology, environmental policy stringency, and political globalization: Pathways to achieving sustainability

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Abstract

This study examines the effects of technology patents, environmental policy stringency, and political globalization on green energy markets and energy transitions in 18 OECD countries from 1990 to 2022. Two models—one focusing on renewable energy and the other on non-renewable energy—were analyzed using Method of Moments Quantile Regression (MMQR), which accounts for outliers and nonlinear relationships. The results demonstrate that technological advancement and stringent environmental policies promote the adoption of renewable energy. Additionally, political globalization shows a positive correlation with green energy while negatively impacting fossil fuel use. The study offers policy recommendations for advancing green energy transitions aligned with the net-zero carbon agenda.

Keywords: Patents on technology; Environmental policy stringency; Political globalization; MMQR; Climate change; OECD

1. Introduction

In the face of escalating climate change, the global shift toward a low-carbon economy has become increasingly urgent. Fossil fuels, which still account for approximately 80% of global energy consumption (Irfan et al., 2023), are major contributors to greenhouse gas emissions and environmental degradation. As nations strive to meet the targets set by international agreements such as the Paris Agreement—which aims to limit the global temperature increase to 1.5°C (UNO, 2021)—renewable energy sources have emerged as essential alternatives. These green energy sources offer the promise of cleaner, more sustainable energy production, yet the transition from fossil fuels is complex and fraught with challenges. This paper addresses the critical factors influencing this transition, focusing on the roles of technology patents, environmental policy stringency, and political globalization across 18 OECD countries from 1990 to 2022.

The shift to renewable energy is necessary but not without significant hurdles. High initial costs, the variability of renewable sources, and the infrastructure required to integrate green energy into national grids pose substantial barriers (Wang & Taghizadeh-Hesary, 2023). Moreover, fossil fuel industries, deeply entrenched in both global markets and political systems, continue to resist rapid transitions. Despite these obstacles, green energy markets are crucial for reducing the environmental impact of energy consumption and ensuring long-term sustainability and energy security. As the demand for clean energy grows, effective policy frameworks and technological advancements are vital for driving this transition.

Technological innovation plays a pivotal role in enabling the large-scale adoption of renewable energy. Patents in green technologies—especially those related to renewable energy generation, storage, and grid integration—are crucial for fostering innovation and attracting private sector investment in research and development (Razzaq et al., 2022). Patents provide intellectual property protection, which incentivizes companies to invest in developing new technologies that can make renewable energy more efficient and cost-competitive with fossil fuels. Previous research has shown that technological advancements are key drivers in improving energy efficiency and reducing the environmental footprint of energy consumption (Chen et al., 2021; Zhang et al., 2022). However, the study contributes to the literature by emphasizing that while technology patents are necessary, they are not sufficient on their own to drive the green energy transition.

In addition to technological innovation, stringent environmental policies are necessary to create the economic and regulatory conditions that prioritize clean energy. Environmental policy stringency (EPS) refers to the degree to which governments enforce regulations aimed at curbing environmentally harmful activities, such as carbon emissions, and promoting sustainable energy practices. Policies like carbon taxes, emissions trading systems, and renewable energy subsidies can help internalize the environmental costs of fossil fuel use, making clean energy alternatives more competitive (OECD, 2022). Stringent environmental policies not only encourage businesses to invest in cleaner production processes but also incentivize consumers to make environmentally friendly choices (Rehman et al., 2023). This paper contributes to the existing literature by demonstrating how EPS supports the energy transition through regulatory mechanisms, helping to drive investments in renewable energy sources (e.g., Nguyen et al., 2021; Pham et al., 2020). Furthermore, the findings indicate that EPS positively influences renewable energy consumption while negatively impacting non-renewable energy use, highlighting its dual role in promoting sustainable development.

Political globalization is another critical factor shaping the global energy transition. Political globalization refers to the increasing interconnectedness of countries through international agreements, organizations, and cooperation on environmental issues (Pata & Caglar, 2021). Through multilateral institutions like the United Nations Framework Convention on Climate Change (UNFCCC) and the Organisation for Economic Co-operation and Development (OECD), countries can collaborate to set common environmental goals and share best practices for reducing greenhouse gas emissions and increasing renewable energy adoption. International agreements facilitate the dissemination of technologies and policies that support the green energy transition. Political globalization not only fosters cooperation but also holds countries accountable to their international commitments, furthering the global push for carbon neutrality (Appiah et al., 2023). This paper uniquely contributes to these strands of literature by examining how political globalization interacts with both technology and policy to enhance the adoption of renewable energy.

More specifically, this research aims to make three key contributions to the existing body of knowledge on environmental policy and the transition to a low-carbon economy. *Firstly*, while prior research has explored the impact of patents on technology and EPS individually (e.g., Fareed et al., 2022; Qi et al., 2022; Yang et al., 2022), the role of political globalization effect in the green energy transition remains understudied. Following the current literature (Wang & Taghizadeh-Hesary, 2023), which shows green investments increase renewable energy consumption in OECD countries. This study addresses this gap by examining *how does globalization help to accomplish the zero-carbon agenda, considering patents on technology and environmental policy stringency in green energy transition.* This exploration provides a novel perspective on the interplay between political globalization and technological and policy factors in driving the energy transition by employing the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) theoretical framework. A key practical takeaway is the importance of understanding the extent to which clean energy can effectively replace fossil fuels in this transition. *Secondly*, motivated by our main research question, we employ a robust methodology to analyze the complex relationships between technological innovation, EPS, and political globalization. In particular we use preliminary panel estimations, including 2nd generation unit root tests, cross-sectional dependence (CSD), and cointegration tests. The method of moments quantile regression (MMQR) (Machado & Silva, 2019) is applied to investigate the influence of the explanatory variables on both renewable (Model A) and non-renewable energy (Model B) consumption in OECD economies for the period 1990-2022. This estimation is robust to outliers and offers a nonlinear connection among variables by applying distinct quantile distributions. Our findings suggest that stringent environmental policies and advancements in technology support the adoption of energy transition, emphasizing the use of renewable energy sources. The findings also indicate that political globalization positively influences green energy while negatively impacting the reliance on fossil fuels. Finally, the study offers concrete policy recommendations based on its empirical findings, guiding governments and stakeholders in shaping effective strategies to accelerate the transition to renewable energy while reducing reliance on fossil fuels.

The analysis is based on data from 18 OECD countries over the period from 1990 to 2022. The OECD countries were chosen for their advanced economies, which have demonstrated significant progress in both industrialization and environmental policy implementation (Appiah et al., 2023). Additionally, the OECD has experienced considerable environmental damage due to infrastructure expansion, urbanization, and industrialization (Appiah et al., 2023). According to the Global Footprint Network (GFN), the OECD is responsible for more than 42% of the global ecological footprint (GFN, 2023). Also, the Ecological Footprint (EFP) Per Capita in these countries ranges from 0.5 to 4.5, with an average score of 2.06, rising from 0.20 in 1990 to 4.5 in 2020. Consequently, these relatively high scores indicate that the OECD is making significant progress in implementing strict environmental policies aimed at achieving the Sustainable Development Goals (SDG 13). The two models used in this study—Model A for renewable energy consumption and Model B for non-renewable energy consumption—provide a comparative framework for understanding how different variables influence energy transitions in these industrialized nations. By employing the MMQR approach, the study is able to capture the varying impacts of technology, policy, and globalization across different levels of energy consumption, offering a comprehensive analysis of the factors driving the green energy transition.

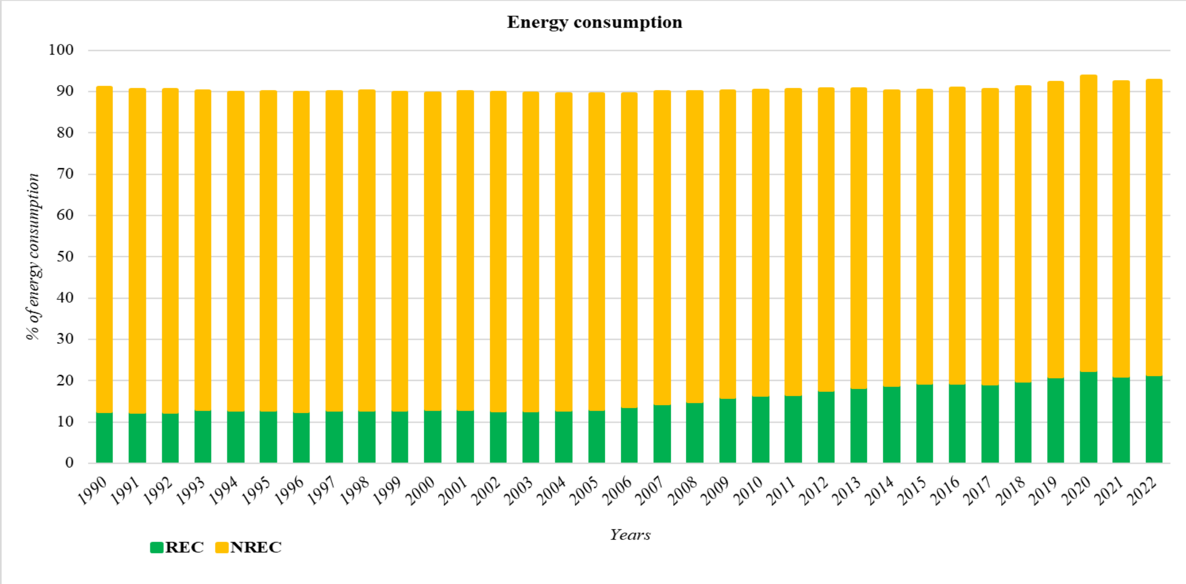
Our paper addresses the critical nexus of technology, environmental policy, and globalization in driving the shift to renewable energy. The findings highlight the importance of integrating technological innovation with stringent policy frameworks and international cooperation to achieve meaningful progress toward a low-carbon economy. By providing actionable insights and policy recommendations, this research contributes to the ongoing efforts to accelerate the adoption of renewable energy and achieve the ambitious targets set by the Paris Agreement and other global initiatives. Ultimately, the study underscores the need for a holistic approach that combines innovation, regulation, and global collaboration to ensure a sustainable energy future.

We manage the remainder of the study structure in the following manner. Section 2 presents the description of the theoretical underpinning of study variables, whilst Sections 3 and 4 report the research methodology and outcomes, respectively. Finally, Section 5 states the results, discussion, conclusion, and policy implications for the OECD governments.

2. Literature review and theoractical framework

2.1 Environmental policy and technology

Since the Conference of Parties (COP) held in Paris in 2015, numerous studies have shown the interlinkages between innovation, environmental policies, and environmental quality. The ecological factors-environmental quality nexus has received much attention in the extant literature on climate change economics (Irfan et al., 2023; Ren et al., 2022) as reported in Table 1. Among the factors that influence the enhancement of energy security, technical advancement is regarded as the most effective and significant means to increase energy efficiency (Chen et al., 2021; Zhang et al., 2022). Many academics have affirmed that high-tech progress reduces energy intensity and enhances energy efficiency (Adu et al., 2023; Yang et al., 2022). Figure 1 illustrates the tendency of renewable and traditional energy consumption for the period of 1990 to 2022 for 18 OECD economies. Since 1990, cleaner energy consumption has increased gradually and almost doubled in developed nations in three decades. This asserts that modern economies are becoming more dependent on renewable energy means. Contrarily, the percentage share of traditional energy is decreasing in total energy usage in OECD countries.



Fiure. 1. *Energy consumption in 18 OECD countries for the period 1990-2022. Model A (REC) denotes renewable, whereas Model B (NREC) illustrates non-renewable energy consumption.*

The primary concept outlined in Porter & Linde (1995) has shown how strict environmental laws encourage eco-innovation and improve the environmental performance of the companies. Although producers and consumers have the financial burden of complying with environmental standards, society benefits from a cleaner environment. More specifically, a new regulation's shock value may alert businesses to possible resource efficiencies and technological advancements, which could spur innovation and further offset the costs of compliance (Deka et al., 2019; Ramanathan et al., 2017). Strictly enforced environmental laws and policies also improve the quality of the environment by promoting investments in eco-friendly advancement rather than the development of conventional technology, all of which serve to lessen the adverse effects of pollution on environmental quality. Furthermore, strict environmental restrictions incentivize manufacturers and consumers to use cleaner technology (Li et al., 2019). Based on similar reasoning, the Porter hypothesis (Porter & Linde, 1995) suggests that sensible environmental laws stimulate investment in creative ways to advance green technologies (Razzaq et al., 2021) and open the door for economic expansion. Advocates of the Porter hypothesis claim that environmental economists further clarify that stringent environmental regulations push economies away from polluting production and focus on cleaner manufacturing processes. Economic growth can help to improve sustainable environmental growth due to strict environmental policies.

2.2 Environment and political globalization

There has been limited scholarly inquiry into the specific implications of globalization on renewable energy prior to 2013 as shown in Table 1. The bulk of existing studies primarily examine general globalization's influence on overall energy consumption. Subsequently, researchers have progressively initiated investigations into the influence of globalization on green energy markets (Zhang et al., 2021). Most of the research focuses on a specific country, for instance, the United States (Shahbaz et al., 2017), Turkey (Ozcan et al., 2022), or certain countries within a particular area, like African nations (Jeetoo, 2022), European Union (EU) countries (Bayar et al., 2020) and Asia-Pacific countries (Khezri et al., 2021). However, a limited number of studies have directed their attention toward exploring the interconnection between globalization and cleaner energy[1] from an OECD nation's perspective. The utilization of specific representative countries may need to accurately depict the inclusive impact of globalization on energy transition. However, including advanced countries in this research endeavor may mitigate the potential sample bias from a few nations (Nan et al., 2022; Zhang et al., 2023). For instance, Khezri et al. (2021) discovered that globalization (trade openness) encourages renewable energy development. Using autoregressive distributed lags and time-series data in Bangladesh, Doytch & Narayan (2016) revealed that FDI (globalization)[2] inflows encourage the shift toward cleaner energy by raising the share of green energy.

2.3 Environment and financial inclusion

Murshed (2020) discovered that trade openness delays the switch to clean energy and hinders sustainable means. A plausible explanation for the inconsistent results observed could be that the pertinent studies mentioned above employ disparate and precise globalization indices (Gozgor et al., 2020). In addition, Bayar et al. (2020) found that economic globalization has a one-directional causal relationship with green energy for EU transition economies from 1995 to 2015 using the panel Granger causality test. Furthermore, Gozgor et al. (2020) argued that energy transition for OECD nations is promoted by more economic globalization[3] using Panel-Corrected Standard Errors (PCSE) and Fully Modified Ordinary Least Square (FM-OLS) methodologies. Padhan et al. (2020) and Ozcan et al. (2022) emphasized the need for social and political globalization in addition to economic globalization to advance renewable energy.

In the case of financial inclusion[4], which refers to providing suitable and cost-effective products to enterprises and individuals, facilitating their access to credit and insurance,

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[1] *The energy transition is not solely limited to a specific country or region but rather a crucial undertaking for all nations to attain balanced development.*

[2] *Existing research, however, has yet to come to a unanimous conclusion.*

[3] *Despite efforts by researchers to employ encompassing globalization metrics to assess their effects on the environment, the indicators solely gauged economic globalization, neglecting other facets such as social and political globalization.*

[4] *The subject of financial inclusion has garnered significant scholarly interest in recent years. However, there needs to be a comprehensive and standardized calculation methodology to assess financial*

enabling financial transactions, facilitating payments, and promoting savings (WDI, 2022). The current body of research examines the association between financial development and economic factors, such as growth, innovation, employment, poverty, and the environment. Various scholars have conducted these studies and have explored the interconnections between financial inclusion and these different aspects. These studies have revealed that enhanced financial inclusion has a substantial impact on mitigating energy poverty (Dogan et al., 2021).

2.4 Theoratical framwork

Following the extant body literature, this study inspects the determinants of renewable and non-renewable energy production, relying on the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) theoretical framework in environmental economics, just as the baseline model relies on Dietz & Rosa's (1997) seminal work. This approach is likely to be more detailed in its investigation of the causes of environmental hazards, as it explains the critical components of the STIRPAT model, namely population, wealth, and technology. The Environmental Effect, Population, Affluence, and Technology (IPAT) model introduces the STIRPAT theory. In this case, Model A and B (renewable and non-renewable energy) denote environmental effects; population presents political globalization, whilst affluence and technology report financial inclusion and patents on technology, respectively. The STIRPAT approach is further enlarged with Environmental Policy Stringency and Gross Domestic Index following the Porter hypothesis (Porter & Linde, 1995).

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inclusion (Goel & Sharma, 2017). Typically, financial inclusion is evaluated using two primary categories: accessibility and utilization of financial services (Yorulmaz, 2013; Tram et al., 2021).

Table 1 Literature Review

Sr.	Author (s)	Journal	Country/ Region	Time-period	Variable (s) Considered	Methodology	Study's outcomes
1	Appiah et al., 2023	Technological Forecasting & Social Change	29 OECD countries	1990-2020	EP, REC, Tech & EFP	CS-ARDL & DH causality	Environmental policy reduces the ecological footprint, depending on bio-capacity and industrialization levels. Renewable energy also contributes positively to reducing the EFP.
2	Dogan et al., 2021	Energy Economics	Turkey	11,595 Households	EPY & FI	Logistic regression	Financial inclusion significantly reduces energy poverty, with a stronger impact on female-headed households.
3	Hassan et al., 2024	Energy Economics	32 OECD countries	1990-2019	EPS & REC	GMM & Quantile regression	Stricter environmental policies and technical support positively impact renewable energy adoption through both market and non-market-based approaches.
4	Irfan et al., 2023	Energy Economics	G-7 & E-7	1990-2019	REC, ET, MM, FD, NREC & GDP	CS-ARDL, AMG & CCEMG	Mineral markets drive the energy transition towards low-carbon power in G-7 countries, while FD hinders this transition but has an insignificant impact in E-7.
5	Lee & Yahya, 2024	Energy Economics	184 countries	1969-2022	EI, ES, ERS, FO & MPI	Quantile regression	FO effectively mitigates energy instability, especially at higher levels, while a closed financial system offers partial relief.
6	Murshed, 2020	Renewable Energy	71 countries	2000-2017	REC, NREC & TO	IV & 2SLS	Overall, greater TO effectively aids RE transition in low-income economies but extends transition periods.
7	Nan et al., 2022	Energy Economics	111 countries	1983–2017	CO2, Glob. & EC	SPM	CO2 emissions from neighbouring countries positively spill over into the local country. Globalization itself has no significant effect on local CO2 emissions.
8	Nepal et al., 2024	Energy Economics	China	2010-2021	RETI & GF	Difference-in-difference	Pilot zones have significantly and positively impacted RETI, with this effect primarily observed in China's eastern regions.
9	Ozcan et al., 2022	Renewable Energy	Turkey	1980-2017	REC, Glob. & HC	D-ARDL	Globalization, particularly its economic and political aspects, significantly boosts REC, while social globalization has no significant impact on REC.
10	Rehman et al., 2023	Journal of Cleaner Production	Emerging-7	1970–2020	REC, CFP, Glob & HC	CS-ARDL	The results show that financial globalization increases the carbon footprint, while HC, technological advancement, and RE enhance environmental performance.
11	Shinwari et al., 2024	Energy Economics	29 BRI economies	2000-2021	EC, FDI & GT	Driscoll-Kraay, FGLS & PCSE	Global FDI positively influences energy consumption, with China's FDI dominance also boosting energy use.
12	Sirin & Yilmaz, 2024	Energy Economics	S&P 500 firms	2009-2021	ET, FP & Business	Granger causality	Capability-based energy transition strategies positively moderate the relationship between REC sector performance and non-energy firms' financial performance.
13	Sohag et al., 2024a	Energy Economics	OECD countries	1990–2018	EFP, EP, REC & Innovation	CS-ARDL	Environmental policy reduces EFP via RE and innovation, with its effectiveness depending on a country's bio-capacity and industrialization level.
14	Sohag et al., 2024b	Energy Economics	OECD Countries	1990-2020	PS, EI, SD & EP	DRF	Policy stringency has a mixed environmental impact. However, implementing PS notably reduces per capita carbon emissions and decreases ecological footprint.
15	Wang & Taghizadeh-Hesary, 2023	Energy Economics	15 OECD Countries	2010-2020	REC, GB & GF	FM-OLS	Green bonds boost wind and hydro-energy consumption in OECD countries but have little impact on solar energy deployment
16	Zhang et al., 2021	Energy Economics	35 OECD countries	1998-2018	REC & TO	PSTR	Empirical results reveal a strongly nonlinear relationship between trade openness and renewable energy consumption.
17	Zhang et al., 2024	Energy Economics	China	2011-2019	EDP, EE & GTI	Difference-in-difference	The EDP significantly boosts the GTI of EEs, primarily through green invention patents, including energy-saving and alternative energy patents.

Notes: *The abbreviations are as follows: Organization for Economic Cooperation and Development (OECD), Environmental policy stringency (EPS), Renewable Energy Consumption (REC), Generalized Method of Moments (GMM), Ecological Footprints (EFP), Environmental policy (EP), Cross-sectional Augmented Autoregressive Distributed Lag (CS-ARDL), Group of Seven (G-7), Emerging Seven (E-7), Energy Transition (ET), Mineral Markets (MM), Financial Development (FD), Non-renewable Energy Consumption (NREC), Gross Domestic Product (GDP), Augmented Mean Group (AMG), Common Correlated Effects Mean Group (CCEMG), Green Bonds (GB), Green Finance (GF), Fully Modified Ordinary Least Squares (FM-OLS), Technology (Tech.), Dumitrescu-Hurlin (DH), Trade openness (TO), Panel Smooth Transition Regression (PSTR), Financial Performance (FP), Carbon Footprint (CFP), Globalization (Glob.), Human Capital (HC), Carbon Dioxide Emissions (CO2), Economic Complexity (EC), Spatial Panel Model (SPM), Renewable energy technology innovation (RETI), Policy stringency (PS), Environmental indicators (EIS), Sustainable development (SD), Environmental policies (EP), Dose response function (DRF), Instrumental Variable (IV), Two Stage Least Square (2SLS), Energy Poverty (EPY), Financial Inclusion (FI), Energy Instability (EI), Energy Security (ES), Exchange Rate Stability (ERS), Financial openness (FO), Monetary Policy Independence (MPI), Energy Demonstration policy (EDP), Energy enterprises (EE), Green technology innovation (GTI), Energy consumption (EC), Foreign direct investments (FDI) and Green technologies (GT), Feasible Least Squares (FGLS), and Panels Corrected Standard Errors (PCSE).*

3. Data and methodology

Motivated by the study objectives, this research examines the influence of patents on technology (PET) (Khezri et al., 2021), environmental policy stringency (EPS) (Wang & Taghizadeh-Hesary, 2023), political globalization (PGL) (Rehman et al., 2023a) , financial inclusion (FI) (Dogan et al., 2021; Horky & Fidrmuc, 2024), and gross domestic product (GDP) (Fareed et al., 2022; Koomson et al., 2021) on renewable energy consumption (REC) (Achim et al., 2024; Wang & Taghizadeh-Hesary, 2023) and non-renewable energy consumption (NREC) (Achim et al., 2024; Horky & Fidrmuc, 2024) by using annual panel data of selected 18 OECD countries[5] for the years 1990-2022. Renewable energy (percentage of whole energy) and non-renewable energy (percentage of whole energy) are collected from World Development Indicators (WDI). The data on patents on technology (patents on environment technologies, expected direction $\frac{\delta \text{PET}}{\delta \text{REC}}>0$ and $\frac{\delta \text{PET}}{\delta \text{NREC}}<0$) and environmental policy stringency (environmental policy stringency index, expected direction $\frac{\delta \text{EPS}}{\delta \text{REC}}>0$ and $\frac{\delta \text{EPS}}{\delta \text{NREC}}<0$) are retrieved from the OECD. Moreover, the data on political globalization (political globalization index, expected direction $\frac{\delta \text{PGL}}{\delta \text{REC}}>0$ and $\frac{\delta \text{PGL}}{\delta \text{NREC}}<0$) are retrieved from KOF Swiss Economic Institute.

Financial inclusion (financial access, efficiency, and depth of a country, expected direction $\frac{\delta \text{FI}}{\delta \text{REC}}$ and $\frac{\delta \text{FI}}{\delta \text{NREC}} > 0$) and gross domestic product (constant 2015 US$, expected direction $\frac{\delta \text{GDP}}{\delta \text{REC}}$ and $\frac{\delta \text{GDP}}{\delta \text{NREC}} > 0$) are aggrandized from International Monetary Fund (IMF) and WDI, respectively as reported in Table 2.

Table 2 Variable description.

Variable Name	Symbol	Measurement Unit	Source
Renewable energy consumption	**REC**	Renewable energy consumption (% of total final energy consumption)	WDI
Non-renewable energy consumption	**NREC**	Fossil fuel energy consumption (% of total)	WDI
Patents on technology	**PET**	Patents on environment technologies	OECD
Environmental Policy Stringency	**EPS**	Environmental policy stringency index	OECD
Political globalization	**PGL**	Globalization political index	KOF
Financial inclusion	**FI**	Financial access, efficiency and depth of development	IMF
Gross domestic index	**GDP**	Gross domestic index (constant 2015 US$)	WDI

[55]*Appendix 1A illustrates the list of selected 18 OECD economies.*

Notes: *WDI represents World Development Indicators, OECD shows the Organization for Economic Cooperation and Development, KOF stands for KOF Swiss Economic Institute and IMF indicates International Monetary Fund.*

The current literature expounds on the variables to draw their possible connection with environmental degradation, for instance, environmental technology (Fareed et al., 2022: Zhang et al., 2022), environmental policies (Deka et al., 2019; Ramanathan et al., 2017), political globalization (Rehman et al., 2023a; Khezri et al., 2021), financial inclusion (Dogan et al., 2021; Koomson & Danquah, 2021) and economic growth (Ali et al., 2022). Hence, the following equations in two panels are framed to meet the objectives of the study:

$$REC_{it} = \beta_O + \beta_1 PET_{it} + \beta_2 EPS_{it} + \beta_3 PGL_{it} + \beta_4 FI_{it} + \beta_5 GDP_{it} + \varepsilon_{it} \quad (3.1)$$

In Eq. 3.1, *i* and *t* indicate the cross sections (18 OECD countries) and time (1990-2022) of the data, respectively. β_O denotes the slope, whereas β_1 to β_5 are coefficients of all the independent variables engaged in this research for Panel A (REC), and ε_{it} shows the residuals. In addition to REC, this study estimates the impact of independent variables to examine the robust results for Panel B (NREC) as shown in Eq. 3.2:

$$NREC_{it} = \beta_O + \beta_1 PET_{it} + \beta_2 EPS_{it} + \beta_3 PGL_{it} + \beta_4 FI_{it} + \beta_5 GDP_{it} + \varepsilon_{it} \quad (3.2)$$

Figures 2 and 3 demonstrate the distributions of renewable and non-renewable energy consumption at four points in time: 1990, 2000, 2010, and 2022 for 18 OECD countries to graphically illustrate the distributions and changes in energy consumption levels. In both the figures, the OECD economies are allocated into 06 levels as defined in the legends, where bright color generally reports greater magnitude whilst pale color represents a lesser value of the variables. The figures show that every developed economy has changed energy consumption blatantly for both models in the given sample time.

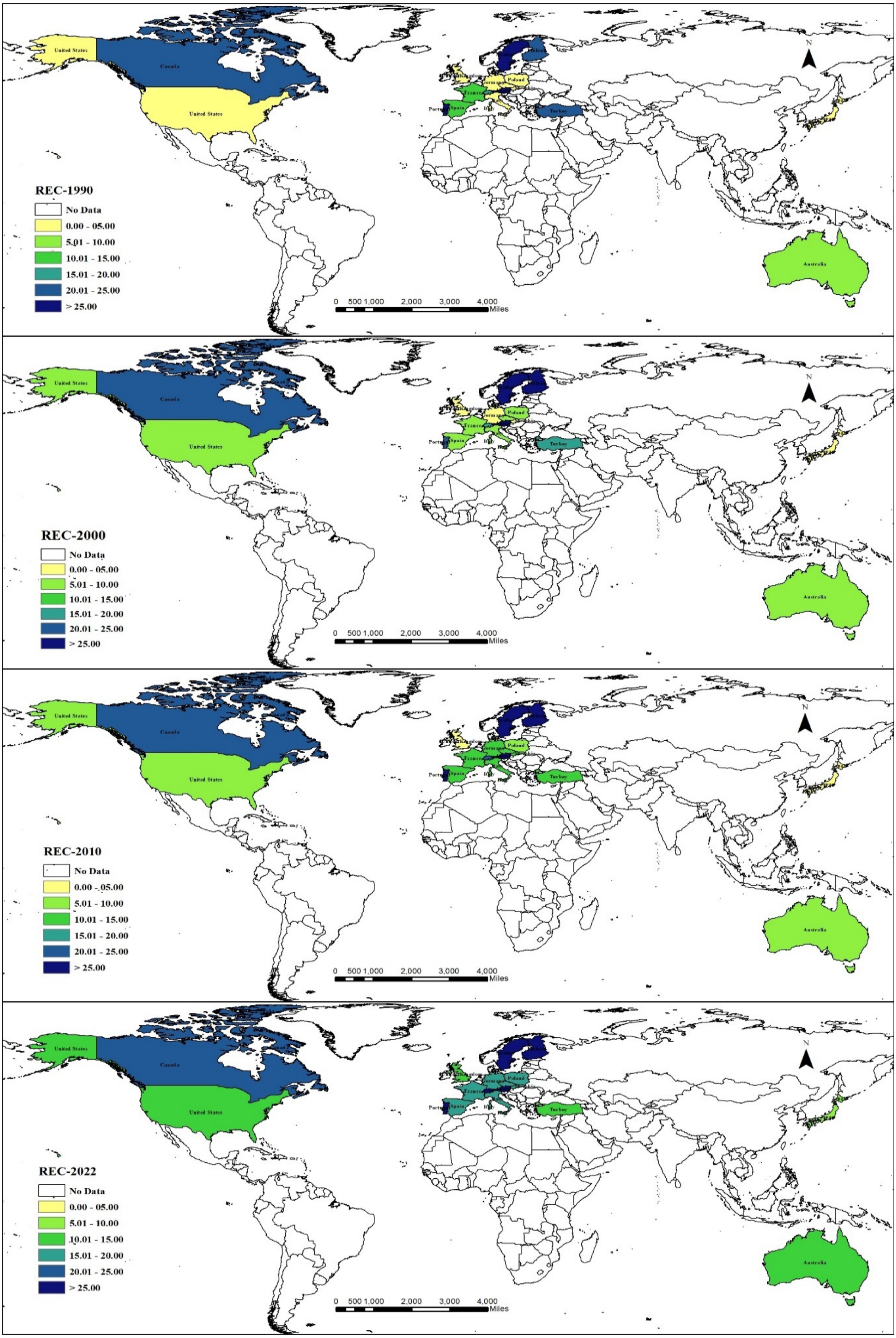

Figure 2. *Distributions of Model A in OECD countries where no data claims the economies outside the research sample. Where REC denotes renewable energy consumption.*

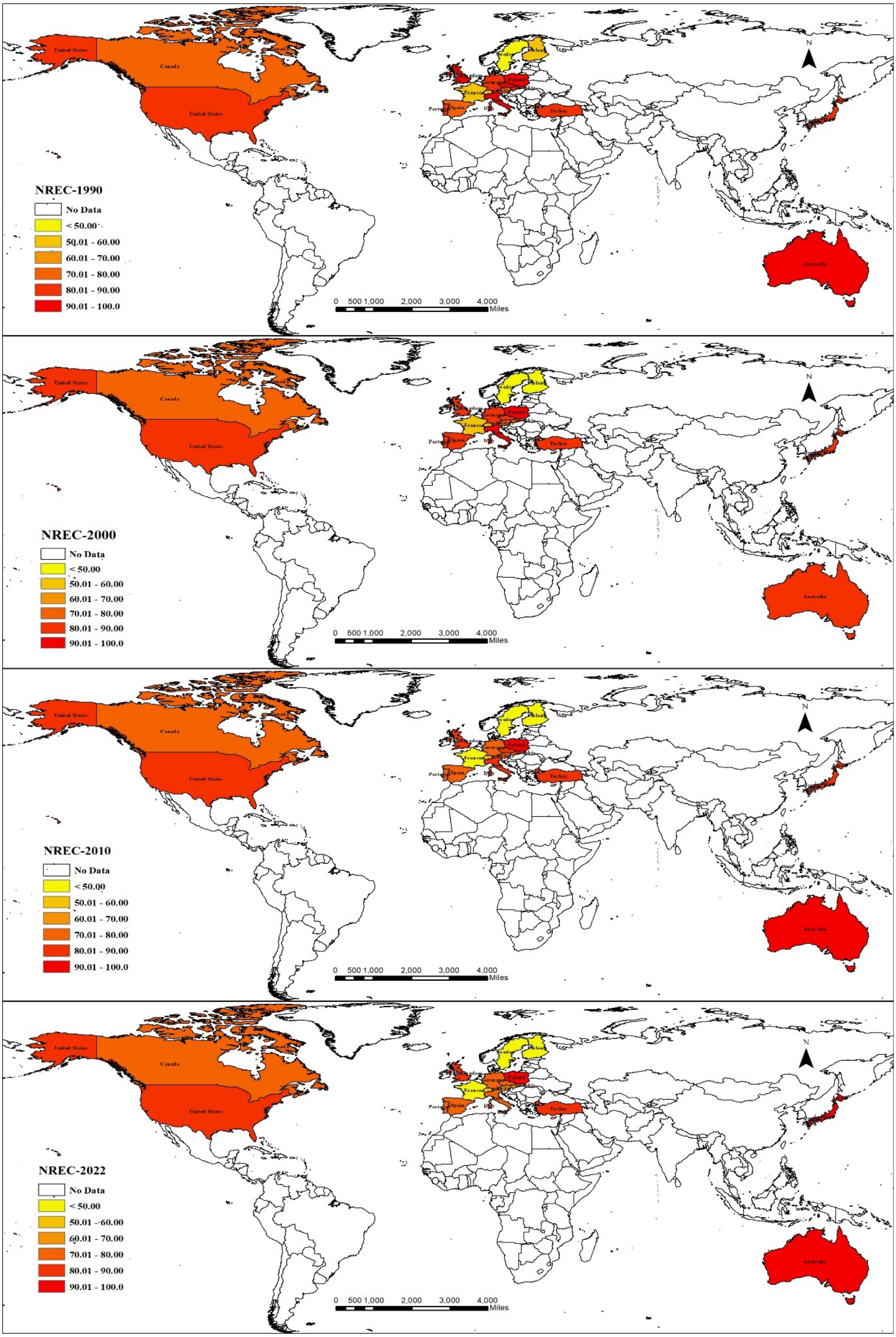

Figure 3. *Distributions of Model B in OECD countries where no data claims the economies outside the research sample. Where NREC denotes non- renewable energy consumption.*

3.1 *Panel Estimation Techniques*

To compare the outcomes of the study, we applied Fully Modified Ordinary Least Square (FM-OLS), Dynamic OLS (D-OLS) (Kao & Chiang, 1999), and Fixed Effect OLS (FE-OLS) techniques (Driscoll & Kraay, 1998). The FE-OLS approach is updated with Driscoll and Kraay standard errors. This estimation is robust and efficient for heterogeneity, autocorrelation, and cross-sectional dependence (Pedroni, 2004). Further, the FM-OLS technique is efficient enough to deal with the heterogeneity, mean difference within cross sections, panel dynamic cointegration, and variations adjusted to cointegrate the equilibrium (Pedroni, 2004). Panel settings are extended with Monte Carlo simulations for D-OLS. It is clarified that the D-OLS approach is unbiased even in a small sample size compared with other estimators. In addition, using lead and lagged differences, endogeneity issues can also be handled with D-OLS.

Koenker & Bassett (1978) initially introduced a quantile regression panel model. This approach was employed to evaluate the dependent variance and conditional mean regarding the magnitudes of explanatory parameters. Quantile regression provides efficient outcomes even if the data have outliers. Following this aim, the authors of this study have applied the Method of Moments Quantile Regression (MMQR) model proposed by Machado & Silva (2019). This statistical technique was proposed to evaluate the distributional effects and is heterogeneous in numerous quantiles (Sarkodie & Strezov, 2019). The location-scale conditional quantile variant estimates $Qy(\tau|X)$ are clarified in Eq. 3.3:

$$V_{it} = \rho_i + X'_{it}\, \omega + (\varphi_i + W'_{it}\, \mu)\, N_{it} \qquad (3.3)$$

where probability P $\{\varphi_I + W'_{it}\, \mu > 0\} = 1$. $(\rho,\, \omega',\, \varphi, \mu')'$ are the estimated parameters. The fixed effects of discrete i are shown by (ρ_i, φ_i), $i = 1, \ldots,$ n, and the recognized elements' k-vector (X) is presented by W, which shows conversions with differential as component l as reported in Eq. 3.4:

$$\mathrm{W_l} = \mathrm{W_l}\,(\mathrm{X}), l = 1, \ldots, \mathrm{k} \qquad (3.4)$$

Where X_{it} is identically distributed across t (time) and i (cross-sections). Likewise, N_{it} is distributed across t, and i, which are orthogonal to X_{it} (Machado & Silva, 2019) such that the remaining parts do not present stringent exogenous behavior. The equation l once again is expressed in in Eq. 3.5:

$$P_y(\tau|X_{it}) = (\rho_i + \varphi_i\, p(\tau)) + X'_{it}\,\omega + W'_{it}\,\mu p\,(\tau) \qquad (3.5)$$

In Eq. 3.4, the independent variables' vectors are denoted by X_{it}: technologies, environmental policies, and political globalization. The independent variables' quantile distribution of V_{it} (for instance, green or traditional energy consumption), as claimed by $P_y(\tau|X_{it})$, is conditional to the location of the independent variables and X'_{it}. – ρ_i (τ) ≡ ρ_i + φ_ip(τ) is the scalar coefficient as presents quantile's fixed effect τ for any cross-section i. Opposite to fixed effects (ordinary least squares), the specific effect does not report a shift in intercept as the parameters are time-invariant; the heterogeneity impacts are acceptable to alter and conditional distribution in the quantiles. $p(\tau)$ reveals the $\tau-$th sample quantiles calculated to determine the resulting optimization problem.

$$min_p \Sigma_i \Sigma_t p_\tau(R_{it} - (\varphi_i + W'_{it}\mu)p) \qquad (3.6)$$

In Eq. 3.6, $p_\tau(A)$ = $(\tau - 1)$ AI$\{A \leq 0\}$ + TAI $\{A > 0\}$ claims the check function.

4. Result estimation

4.1. Preliminary tests

Table 3 reveals the summary statistics of the study variables: renewable energy, non-renewable energy, patents on technology, environmental policy stringency, political globalization, financial inclusion, and GDP. It is reported that the mean value of GDP is the highest (118.386), followed by PGL (90.317) and NREC (74.675). On the contrary, EPS and PET have the lowest mean values. NREC and REC are more volatile among the rest of the study variables in selected OECD economies. The table further elaborates that renewable energy is positive, whereas non-renewable energy is negatively skewed. All the variables have positive kurtosis, indicating leptokurtosis. To estimate the cross-sectional dependence of the study, CSD tests, Breusch-Pagan, and Bias-corrected LM are applied. The results of Table 4 confirm that CSD occurs among the variables as the null hypothesis (H_0) of no CSD is rejected. This phenomenon is due to regional connectivity, economic spillover effects, and globalization (Irfan et al., 2023; Rehman et al., 2023a). With a 1% significance level, the H_0 states the cross-sectional dependence for all variables, according to Table 4. As cross-sectional reliance is legitimate, a shock or change in OECD countries could spread to others. The slope homogeneity (SH) test outcomes are shown in Table 5, following the display of the variables' CSD features. The ignorance of CSD and slope heterogeneity can lead to extrapolations and erroneous outcomes. The table explains and rejects the null claim of slope homogeneity as there are no heterogeneity-related issues.

Table 3 Summary statistics.

Variables	N	Mean	SD	Min	1st Quartile	Median	3rd Quartile	Max	Skewness	Kurtosis
REC	594	15.702	11.392	0.610	6.950	12.535	22.200	58.400	1.113	3.958
NREC	594	74.675	17.145	25.117	65.576	79.780	86.842	98.053	-1.024	3.140
PET	594	6.512	2.122	1.642	4.726	6.932	8.233	10.000	-0.398	2.079
EPS	594	2.281	1.055	0.167	1.389	2.389	3.056	4.889	-0.057	2.135
PGL	594	90.317	6.624	60.795	87.787	91.905	95.272	98.144	-1.631	6.273
FI	594	10.117	3.136	1.760	7.651	9.910	12.340	24.620	0.516	3.734
GDP	594	118.386	6.248	101.054	113.886	117.999	122.927	134.059	0.025	2.714

Notes: *SD represents standard deviations, and N denotes the number of observations. The abbreviations are as follows: Renewable Energy Consumption (REC), Non-Renewable Energy Consumption (NREC), Patents on Technology (PET), Environmental Policy Stringency (EPS), Political Globalization (PGL), Financial Inclusion (FI), and Gross Domestic Product (GDP).*

Table 4 Findings of the cross-sectional dependence tests.

Variables	Panel A		Panel B	
	Breusch-Pagan LM	Bias-corrected LM	Breusch-Pagan LM	Bias-corrected LM
REC	1393.912***	33.980***		
	(<0.001)	*(<0.001)*		
NREC			1400.244***	17.410***
			(<0.001)	*(<0.001)*
PET	1271.854***	101.900***	1271.238***	107.730***
	(<0.001)	*(<0.001)*	*(<0.001)*	*(<0.001)*
EPS	675.713***	84.440***	641.676***	89.040***
	(<0.001)	*(<0.001)*	*(<0.001)*	*(<0.001)*
PGL	1660.885***	20.500***	1645.185***	19.500***
	(<0.001)	*(<0.001)*	*(<0.001)*	*(<0.001)*
FI	765.222***	36.600***	761.489***	31.750***
	(<0.001)	*(<0.001)*	*(<0.001)*	*(<0.001)*
GDP	938.508***	57.000***	964.327***	65.260***
	(<0.001)	*(<0.001)*	*(<0.001)*	*(<0.001)*

Notes: **** claims significance level at 1%. Parenthesis reports the p-values when H_0 = There is no cross-sectional dependence. The abbreviations are as follows: Renewable Energy Consumption (REC), Non-Renewable Energy Consumption (NREC), Patents on Technology (PET), Environmental Policy Stringency (EPS), Political Globalization (PGL), Financial Inclusion (FI), and Gross Domestic Product (GDP).*

Table 5 Findings of the slope heterogeneity test.

Statistics	Test value	Prob.	Test value	Prob.
	Panel A		Panel B	
Tilde (Delta)	19.453***	<0.001	18.774***	<0.001
Adjusted tilde (Delta)	21.916***	<0.001	21.151***	<0.001

Notes: **** claims significance level at 1%.*

After applying CSD and slope heterogeneity tests, the panel non-stationarity test is recommended to double-check the stationarity. It is crucial to observe the stationarity of the variables; for this reason, the authors have applied 1st and 2nd generation unit root tests to investigate the properties of the data. 1st generation: IPS and ADF and 2nd generation unit root tests: CIPS and CADF are applied, as reported in Table 6, to inspect the integration order of the series. Due to CSD and heterogeneity, 2nd generation non-stationarity tests are efficient as endorsed (Rehman et al., 2023a). Outcomes of Table 6 explain that most variables have unit roots at *I(0)*, whereas all are stationary at *I(1)*. Therefore, all the variables are stationary at the ^{first} difference. Figure 4 discovers the correlational plots for all the variables of the study. This two-way figure indicates the binary connection, either positive or negative, from 1990 to 2022.

The long-run relationship between variables can be estimated using the panel's cointegration tests. Hence, this research applies 1st generation tests: Kao, Pedroni, and Westerlund, as shown in Table 7. By rejecting the H_0 of no cointegration, the findings of these tests support the existence of a long-lasting association in the variables' connections. 2nd generation panel Westerlund cointegration test is applied to estimate the likelihood of a cointegrating link between both panels (A: renewable energy and B: non-renewable energy). This test accounts for the issues of CSD and heterogeneity as it has a higher explanatory power than dynamic cointegration tests. Table 8 states P_t and P_a for panel mean and G_t and G_a for group mean statistics. The findings of the table discover that the panel data variables are significantly connected by having long-run relations. Two conditions: coefficients are valuable for estimations, and non-spurious connections are met by following this robust cointegration.

Table 6 Findings of unit root tests (1st and 2nd generation)

Variables	IPS		ADF		CIPS		CADF	
	I(0)	*I(I)*	*I(0)*	*I(I)*	*I(0)*	*I(I)*	*I(0)*	*I(I)*
REC	6.460	-12.938***	6.460	-13.845***	-1.938	-5.769***	0.316	-12.774***
	(1.000)	*(0.000)*	*(1.000)*	*(0.000)*			*(0.624)*	*(0.000)*
NREC	1.895	-14.367***	2.199	-15.156***	-2.504***	-5.679***	-2.413***	-11.623***
	(0.971)	*(0.000)*	*(0.986)*	*(0.000)*			*(0.008)*	*(0.000)*
PET	-4.281***	-13.250***	-4.675***	-14.141***	-2.600***	-5.859***	-2.226**	-11.388***
	(0.000)	*(0.000)*	*(0.000)*	*(0.000)*			*(0.013)*	*(0.000)*
EPS	2.996	-12.376***	3.411	-13.355***	-2.944***	-5.720***	-5.192***	-12.839***
	(0.999)	*(0.000)*	*(1.000)*	*(0.000)*			*(0.000)*	*(0.000)*
PGL	-10.360***	-15.489***	-11.089***	-16.272***	-3.942***	-5.834***	-5.023***	-13.216***
	(0.000)	*(0.000)*	*(0.000)*	*(0.000)*			*(0.000)*	*(0.000)*
FI	-2.373***	-14.454***	-2.412***	-15.020***	-3.515***	-5.889***	-5.708***	-15.776***
	(0.009)	*(0.000)*	*(0.000)*	*(0.000)*			*(0.000)*	*(0.000)*
GDP	0.881	-12.288***	1.143	-13.327***	-2.429***	-4.726***	-3.623***	-8.650***
	(0.811)	*(0.000)*	*(0.874)*	*(0.000)*			*(0.000)*	*(0.000)*

Notes: **** and ** claim significance levels at 1% and 5%, respectively. Parenthesis reports the p-values when H_0 = There is non-stationarity in the series. The abbreviations are as follows: Renewable Energy Consumption (REC), Non-Renewable Energy Consumption (NREC), Patents on Technology (PET), Environmental Policy Stringency (EPS), Political Globalization (PGL), Financial Inclusion (FI), and Gross Domestic Product (GDP).*

Table 7 Findings of 1st generation cointegration tests.

Estimates	**Panel A**		**Panel B**	
	Stat.	**Prob.**	**Stat.**	**Prob.**
	Kao Cointegration Test			
Modified Dickey-Fuller t	-0.278	0.390	-0.579	0.281
Augmented Dickey-Fuller t	1.188	0.118	0.163	0.435
Unadjusted Dickey-Fuller t	-0.734	0.232	-1.488*	0.068
Modified Unadjusted Dickey-Fuller t	-0.872	0.192	-1.359*	0.087
	Pedroni Cointegration Test			
Modified Phillips-Perron t	3.523***	0.000	3.136***	0.001
Augmented Dickey-Fuller t	1.414*	0.079	-0.305	0.380
	Westerlund Cointegration Test			
Variance Ratio	3.675***	0.000	2.1492**	0.0158

Notes: ** and ** claim significance levels at 10% and 5%, respectively, whereas *** reports a 1% significance level. Parenthesis reports the p-values when H_0 = There is no cointegration.*

Table 8 Findings of 2nd generation cointegration test.

Estimates	Panel A				Panel B			
	Gt	Ga	Pt	Pa	Gt	Ga	Pt	Pa
Value	-1.857	-5.563	-7.105	-3.855	-2.378	-6.757	-8.838	-5.168
Z-value	0.819	2.409	0.158	1.525	-1.582	1.602	-1.521	0.529
Prob.	0.794	0.992	0.563	0.936	0.057	0.945	0.064	0.701
Robust Prob.	0.000	1.000	0.000	1.000	0.000	0.000	0.000	0.000

Notes: *H_0 = There is no cointegration.*

The current study reveals the relationship of patents on technology, environmental policy stringency, and political globalization with renewable energy (Panel A) and non-renewable energy (Panel B) in the OECD countries by applying the MMQR statistical estimation. Table 9 states that according to Panel A, PET is positively heterogeneous across all quantiles. As it moves from the lower to the upper quantiles, the positive coefficient magnitude of PET increases, indicating that the impact of technology on REC changes. A 1% increase in PET leads to a rise in REC equal to 1.218%–1.890% in nine quantiles, as reported in existing studies (Chen et al., 2021; Zhang et al., 2022). The positive coefficient value of PET is the highest at the uppermost quantile, indicating that as PET moves, the magnitude of cleaner energy consumption also increases. Contrarily, PET has a negative connection with NREC, asserting that a 1% increase in PET leads to a decline in NREC amounting to 0.821%–2.297% in OCED economies. As the world advances toward a low-carbon economy, green energy markets have emerged as a viable and promising substitute for traditional energy sources. These markets provide the opportunity for green applications that renewable energy sources may efficiently influence. Considering the importance of emerging cleaner energy consumption for environmental sustainability and to lessen the menace of climate change (Wang & Taghizadeh-Hesary, 2023). The estimations further explore how cleaner and traditional energy means are significantly connected with technological policies crucial to recognizing that not all green energy sources are equal in achieving carbon neutrality and net-zero emissions (Karim et al., 2023).

The EPS has a positive and negative relation with the cleaner energy in Panel A and non-renewable energy in Panel B, respectively. Table 9 claims that environmental policies play a crucial role in ecological preservation as a 1% increase in EPS leads to a rise in REC equal to 2.002%–4.878% in nine quantiles. In the case of Panel B, EPS forces countries to reduce dependence on NREC to meet the carbon neutrality targets. These findings are consistent with the current literature (Deka et al., 2019; Ramanathan et al., 2017). By creating a marketplace that incentivizes and values sustainable energy production as well as consumption that provides a pathway towards a low-carbon future. Furthermore, green energy technologies hold tremendous potential to meet our energy demand by minimizing the environmental influence associated with traditional means. So, successfully integrating green energy in the energy sector requires more than just technological advancements.

Table 9 further explains that political globalization has a positive relationship with green energy and a negative connection with fossil-fuel-based energy consumption. These heterogeneous effects are evident across all the given quantiles. PGL increased from 0.608 in the first quantile to 0.822 in the ninth quantile for Panel A, whereas the coefficients of the PGL in Panel B decreased from the lesser to the greater quantiles, indicating that more PGL becomes a noble cause to preserve the environmental degradation; these results are aligned with the literature (Khezri et al., 2021; Ozcan et al., 2022). In the case of financial inclusion, the findings of MMQR estimate that FI is directly related to both panels, asserting that more financial inclusion can lead towards renewable and traditional energy consumption; however, its coefficient is more robust with NREC. Similarly, economic growth is also unfavorable for environmental support as economies become desperate to consume more energy (Ali et al., 2022) and resources to meet their economic demand and sometimes ignore the sustainable global agenda (Dogan et al., 2021; Irfan et al., 2023).

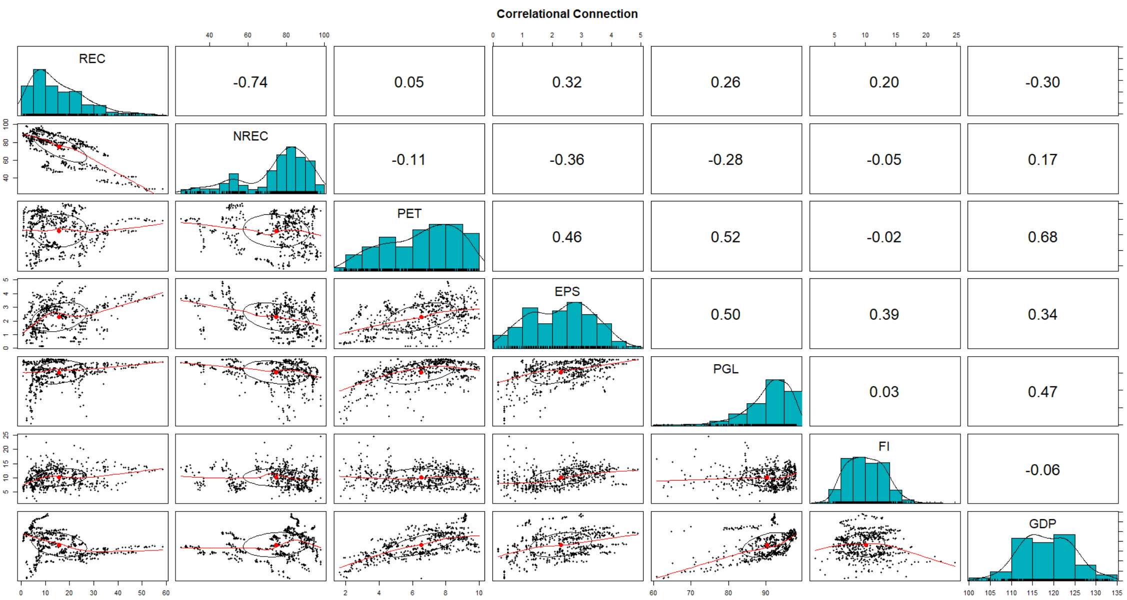

Figure 4. *Correlational plots in selected OECD countries. The abbreviations are as follows: Renewable Energy Consumption (REC), Non-Renewable Energy Consumption (NREC), Patents on Technology (PET), Environmental Policy Stringency (EPS), Political Globalization (PGL), Financial Inclusion (FI), and Gross Domestic Product (GDP).*

Table 9 Findings of the MMQR test.

Variables	Location	Scale	Quantiles								
			10th	**20th**	**30th**	**40th**	**50th**	**60th**	**70th**	**80th**	**90th**
Panel A: Renewable Energy Consumption											
PET	1.497***	0.229	1.218***	1.271***	1.318***	1.351***	1.410***	1.504***	1.648***	1.793***	1.890***
	(0.256)	*(0.163)*	*(0.192)*	*(0.190)*	*(0.195)*	*(0.202)*	*(0.221)*	*(0.261)*	*(0.338)*	*(0.427)*	*(0.489)*
EPS	3.197***	0.981**	2.002***	2.230***	2.429***	2.570***	2.826***	3.224***	3.842***	4.463***	4.878***
	(0.652)	*(0.414)*	*(0.490)*	*(0.484)*	*(0.496)*	*(0.514)*	*(0.566)*	*(0.669)*	*(0.865)*	*(1.086)*	*(1.243)*
PGL	0.697***	0.073*	0.608***	0.625***	0.639***	0.650***	0.669***	0.699***	0.745***	0.791***	0.822***
	(0.067)	*(0.042)*	*(0.050)*	*(0.050)*	*(0.051)*	*(0.053)*	*(0.058)*	*(0.068)*	*(0.088)*	*(0.111)*	*(0.127)*
FI	0.218	0.075	0.126	0.144	0.159	0.170	0.190	0.220	0.268	0.316	0.347
	(0.153)	*(0.097)*	*(0.114)*	*(0.113)*	*(0.116)*	*(0.120)*	*(0.131)*	*(0.155)*	*(0.201)*	*(0.254)*	*(0.291)*
GDP	-1.359***	-0.192***	-1.125***	-1.169***	-1.208***	-1.236***	-1.286***	-1.364***	-1.485***	-1.607***	-1.688***
	(0.077)	*(0.049)*	*(0.058)*	*(0.057)*	*(0.059)*	*(0.061)*	*(0.068)*	*(0.081)*	*(0.104)*	*(0.129)*	*(0.147)*
Panel B: Non-Renewable Energy Consumption											
PET	-1.602***	-0.491**	-0.821	-1.058**	-1.252***	-1.443***	-1.671***	-1.865***	-2.022***	-2.164***	-2.297***
	(0.373)	*(0.202)*	*(0.573)*	*(0.498)*	*(0.445)*	*(0.403)*	*(0.367)*	*(0.352)*	*(0.353)*	*(0.364)*	*(0.383)*
EPS	-13.107***	1.775***	-15.935***	-15.076***	-14.373***	-13.685***	-12.860***	-12.156***	-11.589***	-11.075***	-10.594***
	(1.002)	*(0.543)*	*(1.540)*	*(1.335)*	*(1.197)*	*(1.088)*	*(0.991)*	*(0.949)*	*(0.950)*	*(0.977)*	*(1.025)*
PGL	-0.812***	0.192***	-1.119***	-1.026***	-0.950***	-0.875***	-0.786***	-0.709***	-0.648***	-0.592***	-0.540***
	(0.100)	*(0.054)*	*(0.153)*	*(0.133)*	*(0.119)*	*(0.108)*	*(0.099)*	*(0.094)*	*(0.094)*	*(0.097)*	*(0.102)*
FI	0.333	0.035	0.277	0.294	0.308	0.322	0.338	0.352*	0.363*	0.374*	0.383*
	(0.219)	*(0.119)*	*(0.336)*	*(0.292)*	*(0.261)*	*(0.235)*	*(0.214)*	*(0.206)*	*(0.207)*	*(0.214)*	*(0.225)*
GDP	1.557***	-0.040	1.621***	1.601***	1.585***	1.570***	1.551***	1.535***	1.522***	1.510***	1.499***
	(0.116)	*(0.063)*	*(0.178)*	*(0.155)*	*(0.138)*	*(0.125)*	*(0.113)*	*(0.109)*	*(0.110)*	*(0.113)*	*(0.119)*

Notes: ** and ** claim significance levels at 10% and 5%, respectively, whereas *** reports a 1% significance level. Parenthesis reports the standard errors. The abbreviations are as follows: Patents on Technology (PET), Environmental Policy Stringency (EPS), Political Globalization (PGL), Financial Inclusion (FI), and Gross Domestic Product (GDP).*

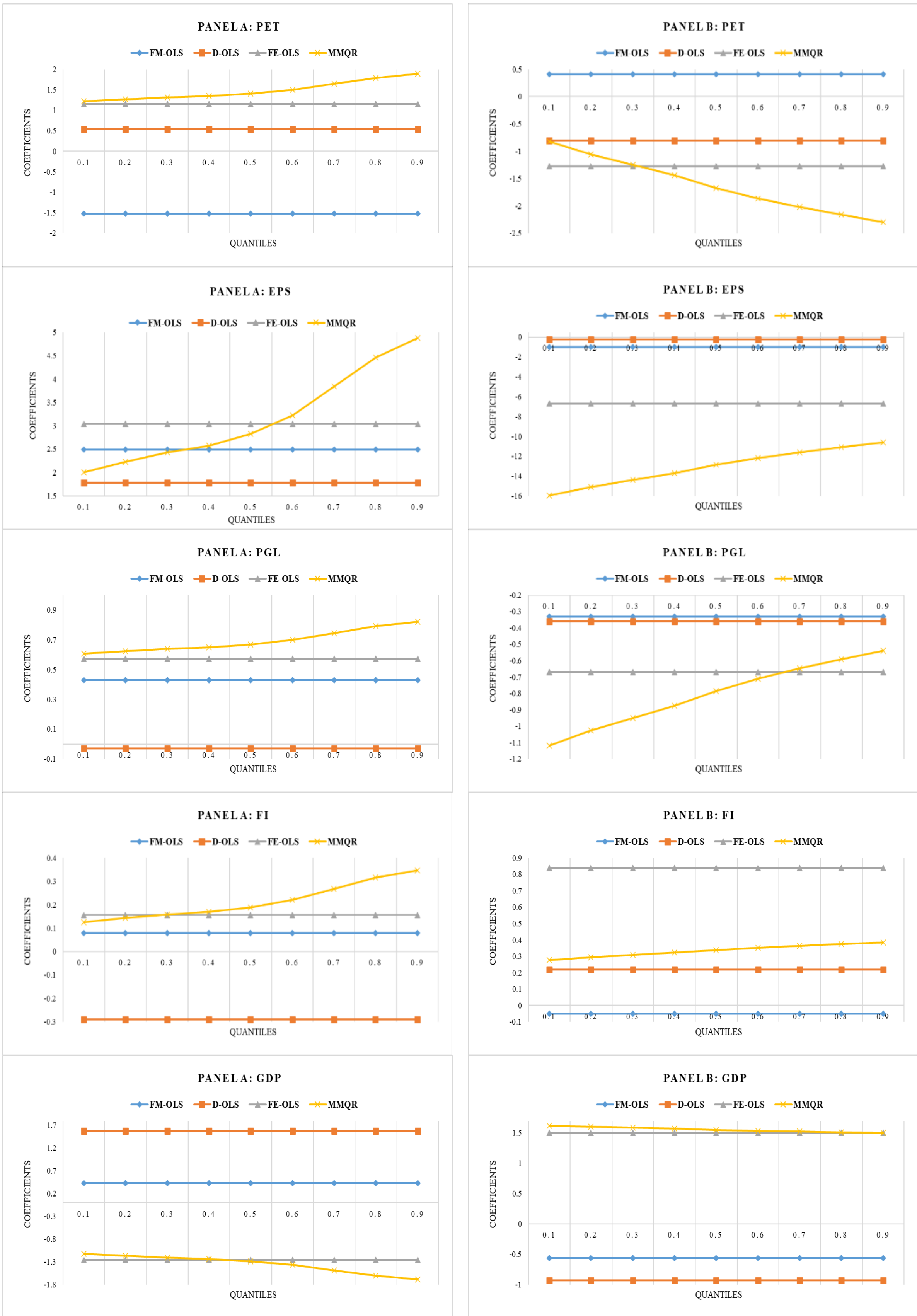

Figure. 5 Coefficients of Fully Modified Ordinary Least Squares (FM-OLS), Dynamic Ordinary Least Square (D-OLS), Fixed Effect OLS (FE-OLS), and Method of Moments Quantile Regression (MMQR) for all the study variables.

Table 10 Findings of the robustness tests.

Variable	FM-OLS		D-OLS		FE-OLS	
	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat
Panel A						
PET	-1.53***	-22.51	0.540***	-15.780	1.157***	2.960
EPS	2.49***	31.23	1.780***	17.740	3.039***	6.740
PGL	0.43***	11.72	-0.030	-1.190	0.571***	5.970
FI	0.08	1.17	-0.290***	-12.970	0.156	1.060
GDP	0.43***	3.13	1.580***	7.080	-1.262***	-8.460
Panel B						
PET	0.41***	3.51	-0.810***	-3.940	-1.274**	-2.400
EPS	-1.01***	-31.86	-0.210***	-6.110	-6.687***	-5.860
PGL	-0.33***	-18.06	-0.360***	-9.720	-0.670***	-4.430
FI	-0.05***	-9.23	0.220	0.690	0.838**	2.090
GDP	-0.56***	3.02	-0.930***	-4.770	1.505***	7.250

*Notes: *** and ** claim significance levels at 1% and 5%, respectively. The abbreviations are as follows: Patents on Technology (PET), Environmental Policy Stringency (EPS), Political Globalization (PGL), Financial Inclusion (FI), and Gross Domestic Product (GDP).*

To evaluate the robustness of the outcomes, this research further estimates whether and how study variables are connected with energy transition. Table 10 states the findings of the panel estimations, including FM-OLS, D-OLS, and FE-OLS, in the two panels. This research is divided into two sections: patents on technology, environmental policy stringency, political globalization, financial inclusion, and gross domestic product have been examined with green and traditional non-renewable energy. Table 10 clarifies that despite the little variations, the findings of the table are robust with the previously reported outcomes of OECD countries. By comparing all the given panel estimators, this research validates that the MMQR provides more efficient estimations of clearly heterogeneous relationships among research variables by improving the significant effects of the variables.

Figure. 5 compares the graphical illustrations of statistical estimations applied in this research, for instance, FM-OLS, D-OLS, FE-OLS, and MMQR. It is clarified from the figure that the coefficients of these estimations are fixed all the time. On the contrary, the coefficients of MMQR approach are heterogeneous by depicting a comprehensive representation across the quantiles. Moreover, this estimation validates the movement of independent variables (either positive or negative) about dependent variables. For this reason, Panel A explains the connection of independent variables with cleaner energy sources, whereas Panel B presents the relation with non-renewable energy means. These relations are aligned with the outcomes of

Table 9. In comparison, it is found that MMQR estimation is an efficient technique to evaluate the outcomes across multiple quantiles that enable the observation of the movement of the coefficient with the dependent variable rather than a single mean estimation and becomes appropriate for arbitrating the significance and coefficient effects of the variables (Fareed et al., 2022: Rehman et al., 2022). Markets for green energy significantly contribute to lowering the price of green energy developments. As the market for renewable energy grows, economies of scale come into play, resulting in reduced costs through technical improvements and better production techniques. Therefore, green energy markets are now compatible with conventional energy sources, opening the door for widespread adoption as a practical, appealing, affordable, and feasible alternative (Karim et al., 2023).

5. Conclusion

From 1990 to 2022, this research investigates the relationship among patents on technology, environmental policy stringency, political globalization, financial inclusion, and GDP with two models: Model A depicts renewable energy, whereas Model B reports non-renewable energy consumption using annual panel data. Following the research objectives, the authors have applied 2^{nd} generation unit root tests, CSD, and cointegration tests. After applying preliminary tests, the authors further employed MMQR estimation to probe the impact of the explanatory variables on energy transition in OECD economies. More so, for the robustness check, this study has used FM-OLS, D-OLS, and FE-OLS to confirm the heterogeneous outcomes of quantile regression.

The outcomes of the results by answering the research question explore that technological markets provide the opportunity for green applications that renewable energy sources may efficiently influence. The estimations further explore how cleaner and traditional energy means are significantly connected with technological policies crucial to recognizing that not all energy sources are equal in achieving carbon neutrality and net-zero emissions targets. The EPS has a positive and negative relation with the cleaner energy in Panel A and non-renewable energy in Panel B, respectively. Green energy technologies hold tremendous potential to meet our energy demand by minimizing the environmental influence of traditional means. Findings further explain that political globalization has a positive relationship with green energy and a negative connection with fossil-fuel-based energy sources.

The 2024 UNFCCC COP29 could be a game-changer for OECD climate policy. Witnessing ambitious actions or strong pressure at the conference might push OECD countries to adopt stricter policies. This could lead to a domestic shift with stricter regulations, industrial transformation, and potential economic opportunities in clean technologies, all depending on how effectively they manage political resistance, economic concerns, and the need for international cooperation. These developments might drive OECD nations to implement stricter environmental regulations, invest heavily in green infrastructure, and foster innovation in clean technologies, while also necessitating budget reallocations and public-private partnerships. Stakeholders in the OECD countries should implement such environmental policies and rules that emphasize the consumption and production of renewable energy, as the empirical findings reveal a positive relationship between such policies and renewable energy, alongside an adverse connection with fossil fuels. Therefore, raising awareness of green energy markets among policymakers in the OECD region is crucial to evaluating the health benefits of renewable energy consumption. Governments should motivate research and investment in green energy technologies (such as wind, solar, and hydro systems) to limit environmental harm.

Politically, heightened climate action could polarize public opinion and necessitate balancing economic growth with environmental sustainability. Environmental policy, technological innovation, and political globalization all contribute to preserving the environment through a focus on green energy transition. It is imperative to continue investing in green energy markets while implementing policy incentives, avoiding conventional sources, and promoting environmental innovation in green technologies that support the transition to a low-carbon economy to fully realize the potential of the green energy markets in achieving carbon neutrality targets. Hence, the OECD governments should recognize the importance of political globalization and the need to draw coalitions to jointly utilize research and development along with environmental policies in reducing environmental footprints by emphasizing realizing their full potential. Investors should be guided to invest in firms mitigating their negative environmental impact by carbon reporting in their financial statements. Ultimately, these changes could bolster OECD countries' leadership in global climate efforts, influencing both domestic policies and international competitiveness.

This study provides significant insights into the impact of stringent climate policies on OECD countries, yet it is not without limitations. Firstly, the analysis primarily relies on existing data sets and models due to its availability, which may not capture the full complexity of emerging climate policy dynamics. The study's scope is also limited to OECD countries, potentially overlooking crucial differences in policy impacts across non-OECD nations. Especially, this study does not include the entire OECD region due to a shortage of data. Additionally, the study does not fully explore the long-term socioeconomic implications of these policies, which could offer a more comprehensive understanding of their effectiveness. Future research should aim to incorporate more diverse data sources, larger time frame and advanced modeling techniques to enhance the robustness of findings. Expanding the geographical scope to include a wider array of countries and contexts would provide a more global perspective. Furthermore, longitudinal studies focusing on the socioeconomic outcomes of stringent climate policies could offer valuable insights into their sustainability and long-term benefits. Addressing these limitations in future research will help to build a more nuanced and complete picture of the global climate policy landscape.

Appendix 1A

Sr.	Country	Sr.	Country
1	Australia	10	Poland
2	Austria	11	Portugal
3	Canada	12	Slovak Republic
4	Czech Republic	13	Spain
5	Finland	14	Sweden
6	France	15	Switzerland
7	Germany	16	Turkiye
8	Italy	17	United Kingdom
9	Japan	18	United States

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